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OPTIMIZING NITROGEN FERTILIZER RESPONSE BY WINTER WHEAT AND RYE

D.B. Fowler, J. Brydon and R.J. Baker
Crop Development Centre
University of Saskatchewan
Saskatoon, Saskatchewan
Canada S7N 0W0

Abstract

Southwestern Alberta has been the traditional winter wheat production area in western Canada. In recent years, the adoption of a practical snow management system, which utilizes no-till seeding into standing stubble immediately after harvest of the previous crop, has resulted in an extension of this production area to include most of the western Canadian prairies. Winter rye is also adapted to the no-till production system developed for winter wheat. Most stubble fields are deficient in available soil nitrogen (N) with the result that N fertilizer is a major input cost in the production of no-till winter wheat and rye. This report summarizes the N response observed in 40 winter wheat and 20 winter rye trials representing a broad range of soil types and environments in western Canada.

N fertilizer did not have a significant influence on heading date, maturity, hectoliter weight or kernel size in most trials. Where a significant N response was detected, maximum differences were a one and two day delay in heading, a two and nine day delay in maturity, a three and three kg reduction in hectoliter weight, and a seven and nine mg reduction in seed size for wheat and rye, respectively. A significant N response was observed more frequently for height. In this instance, the response was not directional and increases up to 25 and eight cm and reductions to nine and nine cm were observed with increased N for wheat and rye, respectively.

The Gompertz equation provided the most complete description of the relationship between protein concentration and total plant-available N. Predicted grain protein concentration from this equation explained 98 and 93 percent of the variability in actual grain protein concentration for wheat and rye, respectively. The N response curves for protein concentration were similar for winter wheat and rye. After an initial lag, protein concentration increased rapidly, and then tailed off at high N levels.

An inverse polynomial function was employed to describe grain and protein yield response to N fertilizer. Predicted yields from these equations explained 96 and 88 percent of the variability in actual grain yield and 94 and 89 percent of the variability in actual protein yield for wheat and rye, respectively. Winter rye demonstrated a greater N use efficiency and yield potential than winter wheat. There was a large interdependence of N response and environmental conditions, especially moisture supply, in determining yield in these trials.

INTRODUCTION

The traditional winter wheat production area in western Canada has been southwestern Alberta. Warm chinook winds in this region moderate winter temperatures and reduce the risk of winterkill to an acceptable level for winter wheat production. Many attempts have been made to produce winter wheat on the remainder of the prairies; but, the frequency of winterkill with conventional production methods, i.e. seeding into a tilled seedbed, prevented its establishment as a viable crop option outside of the chinook region.

The absence of significant progress in the development of super-hardy winter wheat cultivars (Fowler et al. 1983) has resulted in research efforts being directed toward the development of production systems that would allow winter wheat to avoid the worst winter stresses. A practical snow management system, which utilizes direct seeding into standing stubble immediately after harvest of the previous crop (no-till or stubbling-in), has shown the most promise for expanding winter wheat production area in western Canada (Fowler 1983). The success of the management system is best demonstrated by the increase in Saskatchewan's winter wheat production from less than 1000 ha harvested in 1973 to 340,000 and 327,000 ha harvested in 1985 and 1986, respectively. The potential for no-till winter wheat is further emphasized when one considers that winters as severe as the one experienced in 1984-85 are expected to occur only once in 30 to 50 years in this region (Fowler and Entz 1986).

Nitrogen (N) fertilizer is the major input cost in the production of no-till winter wheat in western Canada (Fowler and Entz 1986). Most stubble fields are deficient in available soil N and in high production environments it is common to find soil test results that indicate less than 30 kg ha^{-1} available N. Consequently, responses to N fertilization are usually very dramatic.

Winter rye production in western Canada has traditionally been confined to lighter, less productive soils where erosion and late summer drought are problems. The risks associated with production on these soils are high and there has not been a large incentive to add extra costs in the form of fertilizers. Winter rye is also adapted to the no-till production system developed for winter wheat. As is the case with winter wheat, no-till winter rye usually requires N fertilization to maximize yields.

Cereal protein contains approximately 17.5 percent nitrogen (N). This N is obtained from the soil, and therefore, plant-available soil N has a direct influence on grain protein yield. Most stubble fields are deficient in soil N with the result that grain protein concentrations for no-till winter cereals have been very low, often less than 10 percent (Fowler 1983). Low protein concentrations in winter wheat are usually reflected by "piebald", "yellow berry" or "starchy" kernels. Protein concentrations of greater than 11 percent are preferred for the hard red winter wheat market class, and therefore, if the frequency of piebald kernels is high a sample will be degraded. Consequently, correcting a soil N deficiency usually means extra returns to the producer from both higher yield and better grade (Fowler 1983).

The importance of eliminating N deficiencies in no-till or "stubbled-in" winter cereal production are easily demonstrated. However, characterizing the responses to N fertilization has been more difficult, largely because of a limited data base. This report summarizes data from 40 replicated field trials in which the effect of N fertilization on winter wheat and rye heading date, grain maturity, grain yield, protein concentration, protein yield, hectoliter weight and 1000-kernel weight was measured.

MATERIALS AND METHODS:

A total of 40 fertilizer trials were conducted during the period 1974 to 1986. Trial sites were located throughout all but the southwest corner of the agricultural region of Saskatchewan. This provided nitrogen (N) response data for 40 winter wheat and 20 winter rye site-years representing a broad range of soil types and environmental conditions (Tale 1). The most highly adapted winter wheat and rye cultivars for this region were utilized in these trials. As additional date and new releases become available this resulted in several cultivar changes (Table 1 and 2). The two winter wheat cultivars, 'Sundance' and 'Norstar' have similar grain protein concentrations and yields (Fowler and de la Roche 1984). The winter rye cultivars, 'Frontier', 'Cougar', and 'Puma', have relative grain yields of 84, 90 and 100 percent and grain protein concentrations of 10.5, 9.7 and 8.8 percent, respectively. Protein yields for the rye cultivars were similar.

Experimental design for trials that included both winter wheat and rye was a split plot with species the main plots and N rates the sub-plots. Experimental design for trials that included only winter wheat was a randomized complete block. N treatments were replicated from 3 to 12 times in each trial. With two exceptions (Table 1), trials were direct seeded into standing stubble immediately after harvest of the previous crop (no-till or stubbling-in). Trials were seeded with a small plot hoe-press drill or a commercial minimum tillage drill. Each fertilizer plot was 5.5 m long and 1.2 m wide. Seeding date was between 24 Aug. and 7 Sept. of each year. Phosphate fertilizer (11-55-0 or 11-48-0) was applied with the seed at rates recommended for each soil type. Other elements were not considered limiting. Available N estimates for each

Table 1. Cropping information, cultivar and environment descriptions for 40 winter wheat and 20 winter rye fertilizer trial sites in Saskatchewan, 1974-86.

Location	Year	Previous Crop[†]	Soil: Classification[‡]	Soil: Series	Soil: Texture[‡]	Spring Available Nitrogen (kg/ha)[§]	Cultivar Utilized: Wheat	Cultivar Utilized: Rye	Environmental Conditions[¶]
1. Clair	1974-75	Summerfallow	Black	Yorkton	L	117	'Sundance'	'Frontier'	Average
2. Clair	1975-76	Rapeseed	Black	Yorkton	L	29	Sundance	'Cougar'	Average
3. Clair	1976-77	Rapeseed	Black	Yorkton	L	24	Sundance	Cougar	Average
4. Clair	1976-77	Rapeseed	Black	Yorkton	L	54	Sundance	Cougar	Good#
5. Clair	1976-77	Rapeseed	Black	Yorkton	L	24	Sundance	Cougar	Average
6. Saskatoon	1976-77	Rapeseed	Dark Brown	Sutherland	SiCL	220	Sundance	Cougar	Average[††]
7. Saskatoon	1976-77	Rapeseed	Dark Brown	Sutherland	SiCL	220	Sundance	Cougar	Poor
8. Clair	1977-78	Barley	Black	Yorkton	L	19	Sundance	Cougar	Good
9. Clair	1977-78	Barley	Black	Yorkton	L	47	Sundance	Cougar	Good
10. Saltcoats	1981-82	Barley	Black	Yorkton	L	79	'Norstar'	'Puma'	Average
11. Kipling	1981-82	Winter wheat	Dark Brown	Weyburn	L	47	Nortar	Puma	Poor
12. Saskatoon	1977-78	Rapeseed	Dark Brown	Sutherland	SiCL	65	Sundance	Cougar	Poor
13. Langbank	1981-82	Winter wheat	Dark Brown	Weyburn	L	28	Norstar	Puma	Poor
14. Carnduff	1981-82	Durum wheat	Black	Oxbow	L	62	Norstar	Puma	Poor
15. Saskatoon	1981-82	Barley	Dark Brown	Sutherland	HC	125	Norstar	Puma	Good[††]
16. Wynyard	1981-82	Spring wheat	Black	Oxbow	L	57	Norstar	Puma	Good
17. Clair	1982-83	Winter wheat	Black	Yorkton	L	43	Norstar		Average#
18. Kindersley	1982-83	Winter wheat	Brown	Sceptre	CL	47	Norstar		Poor
19. Watrous	1982-83	Winter wheat	Dark Brown	Weyburn	L	33	Norsar		Average#
20. Meadow Lake	1982-83	Rapeseed	Black	Meadow Lake	C	29	Norstar	Puma	Poor
21. Kelvington	1982-83	Barley	Black	Yorkton	L	155	Norstar	Puma	Average
22. Nipawin	1982-83	Rapeseed	Dark Gray	Shellbrook	FSL	39	Norstar	Puma	Average
23. Paddockwood	1982-83	Rapeseed	Dark Gray	Pelly	L	71	Norstar	Puma	Average
24. Outlook	1983-84	Rapeseed	Dark Brown	Bradwell	FSCL	111	Norstar		Irrigation
25. Clair	1983-84	Barley	Black	Yorkton	L	29	Norstar		Good
26. Clair	1983-84	Rapeseed	Black	Yorkton	L	22	Norstar		Good
27. Paddockwood	1983-84	Rapeseed	Dark Gray	Paddockwood	L	36	Norstar		Good
28. Saskatoon	1983-84	Rapeseed	Dark Brown	Sutherland	C	103	Norstar		Poor
29. Saskatoon	1983-84	Rapeseed	Dark Brown	Sutherland	C	103	Norstar		Poor
30. Strasbourg	1983-84	Winter wheat	Dark Brown	Weyburn	L	19	Norstar		Poor
31. Watrous	1983-84	Winter wheat	Dark Brown	Weyburn	CL	33	Norstar		Poor
32. Outlook	1984-85	Rapeseed	Dark Brown	Bradwell	L	90	Norstar		Irrigation
33. Clair	1984-85	Rapeseed	Black	Yorkton	CL	42	Norstar		Good
34. Strasbourg	1984-85	Flax	Dark Brown	Weyburn	L	58	Norstar		Poor
35. Carlyle	1985-86	Mustard	Dark Brown	Weyburn	L	73	Norstar		Good
36. Paddockwood	1985-86	Rapeseed	Dark Gray	Pelly	L	46	Norstar		Poor
37. Porcupine Plain	1985-86	Summerfallow	Gray Luvisol	Etomami	CL	311	Norstar		Average
38. Hendel	1985-86	Spring wheat	Dark Brown	Elstow	L	100	Norstar		Average
39. Clair	1985-86	Barley	Black	Yorkton	L	47	Norstar		Average
40. Indian Head	1985-86	Barley	Black	Indian Head	HC	44	Norstar		Average

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[†] Rapeseed (Brassica campestris L.), Barley (Hordeum vulgare L.), winter and spring wheat (Triticum aestvum L.), Flax (Linum usitatissimum L.), Mustard (Sinapsis alba L.).

[‡] According to the Canadian System of Soil Classificaiton, 1978. The Canadian Soil Classification terms Black Chernozemic, Dark brown Chernozemic, Brown Chernozemic, Dark Grey Chernozemic and Gray Luvisol infer the United States Soil Classificaiton terms of Udic Boroll, Typic Boroll, Aridic Haploboroll, Boralfic Boroll, Boralf, respectively. L Loam, Si Silty, C Clay, H Heavy, F Fine, S Sandy.

[§] NO_3-N determined for the surface 60 cm when sampled in the early spring of each crop year.

[¶] Irrigation - Approximately 65 cm total growing season moisture
Good - Above average rainfall which was well distributed during the growing season. Moisture reserves adequate to cope with wind and heat stress experienced.
Average - No extended dry periods. Heat and/or wind stress may have been yield reducing factors
Poor - Periodic drought combined with heat and/or wind stress.

[#] Three test sites in the Clair area, one of which caught a heavy thunderstorm in early July.

[††] Received a single irrigation of 5 cm water in late June.

Table 2. Relative agronomic performance of winter wheat and rye cultivars utilized in these studies. Average of 10 station years for the region where the N fertilizer trials were conducted.

		Heading (da)	Maturity (da)	Height (cm)	Hectoliter wt. (kg)	Kernel wt. (mg)	Yield
	a)	Deviation from Puma					% Puma
Puma		0	0	0	0	0	100
Cougar		-1	0	-9	0	-1	90
Frontier		-1	-1	+3	-2	0	84
	b)	Deviation from Norstar					% Norstar
Norstar[†]		0	0	0	0	0	100
Sundance		0	-1	-1	0	-1	100

[†] The main advantages of Norstar over Sundance are improved quality and winter hardiness.

Table 3. Average heading date, maturity and height of winter wheat and rye. See Table 1 for locations.

Location	Heading Date (da/mon)		Date Ripe (da/mon)		Height (cm)	
	Wheat	Rye	Wheat	Rye	Wheat	Rye
1	6/7*	20/6*	8/8**	4/8**	114*(-)	135*(-)
2	27/6	5/6	5/8	31/7	86**(+)	92**(+)
3	20/6	1/6	28/7**	23/7**	86**(+)	94
4	21/6	1/6	1/8	25/7	87**(+)	104**(+)
5	21/6	1/6	31/7	26/7**	82**(+)	90**(-)
6			29/7	20/7	79	101
7			1/8	19/7	75	92
8	28/6	10/6	5/8	1/8	85**(+)	101**(+)
9	26/6	10/6	6/8	2/8	88**(+)	98**(-)

*,** Differences due to increased N fertilizer rates at the significant 5 and 1% probability levels as tested by a F test. Increased nitrogen fertilizer rates delayed heading and maturity and increased (+) or decreased (-) height in trials where significant differences were detected.

site were corrected to include N applied as mono-ammonium phosphate.

Soil samples were collected at each site in the late fall and early spring for nutrient analyses. Available N levels estimated for the surface 60 cm of soil samples collected in the early spring were utilized in this study (Table 1), as these were considered the best estimates of soil available N (Malhi et al. 1985). Soil and fertilizer N were considered to be equally plant-available, and therefore, total available N was calculated as the sum of available soil N to 60 cm depth, as estimated from the soil test, plus added fertilizer N (Heapy et al. 1976, Zentner and Read 1977, France and Thornley 1984, Bole and Dubetz 1986). Fertilizer N was added as early spring broadcast ammonium nitrate (34-0-0) at 0, 34, 67 and 101 kg ha^{-1} at all sites; additional rates of 135, 202 and 303 kg ha^{-1} were also used at some sites.

Soil was moist to a depth of at least 60 cm in the spring at all sites. General environmental conditions were monitored throughout the growing season (Table 1).

Heading date, maturity, height, seed size, grain test weight and yield (8% H_2O) were measured at the appropriate stages. Protein percentages were determined as Kjeldahl N (Nx5.7) or by the Udy dye method (1971), and results are reported on a 14.0% moisture basis. Kjeldahl analyses were utilized to standardize protein concentrations in each trial analyzed by the Udy dye method. Protein percentages were determined by the Kjeldahl method for all trials that included both wheat and rye.

Analyses of variance were conducted to determine the significance of treatment differences within each fertilizer trial. Polynomial, Mitscherlich, logistic and Gompertz equations were considered to describe the relationship between protein concentration and total plant available

N. The following form of the Gompertz equation provided the most complete description of this relationship:

$$Y = C + Ae^{-Be^{-KN}} \qquad (1)$$

where Y = predicted protein concentration (%)

C = minimum protein concentration (%)

A = asymptotic protein concentration achieved at high N levels

B = coefficient that influences point where protein concentration becomes greater than C.

K = coefficient that determines the rate Y increases to A.

N = total available N.

The fertilizer-N response equation (Eq. 2) outlined by France and Thornley (1984) was used to analyze the relationship of winter wheat and rye total grain and grain protein yields to total available N.

This function takes the form:

$$Y = \frac{(1.0 - N/DEP) \times MAX \times N}{N + MAX/SLOPE} \qquad (2)$$

where Y = predicted grain or grain protein yield (kg ha^{-1})

N = total available nitrogen (kg ha^{-1})

DEP = regression coefficient, a constant which accounts for yield depression at high N levels.

MAX = asymptotic yield which could be achieved with high levels of N if no yield depression were to occur.

SLOPE = regression coefficient, the slope of the fertilizer response equation for the first incremental increase in N; fertilizer use efficiency for grain and grain protein production. The maximum grain and grain protein yields of the predicted response curves (Y_{MAX}), and the level of total available N at which maximum yield is obtained (N_{MAX}) were calculated using equations 3 and 4 from France and Thornley (1984).

$$Y_{MAX} = MAX \left(1 - \frac{2\ MAX}{SLOPE \times DEP} \left[(1 + DEP\ \frac{SLOPE}{MAX})^{\frac{1}{2}} - 1\right]\right) \qquad (3)$$

$$N_{MAX} = \frac{MAX}{SLOPE} \left[(1 + DEP\ \frac{SLOPE}{MAX})^{\frac{1}{2}} - 1\right] \qquad \begin{matrix} P_{MAX} \to \infty \\ K_{MAX} \to \infty \end{matrix} \qquad (4)$$

RESULTS AND DISCUSSION

Winter wheat was significantly ($P \leq .01$) later heading, later maturing and shorter than winter rye in all trials where comparisons could be made (Table 3). Winter wheat also had significantly ($P \leq .01$) larger seed size and higher hectoliter weight than rye (Table 4). Winter rye significantly ($P \leq .05$) outyielded winter wheat in 15 out of 19 trials. Yield differences between the two species were not significantly ($P > .05$) different in the remaining four trials. The grain protein concentration of winter wheat was significantly ($P \leq .05$) higher than winter rye in all comparable trials except for locations 2, 6 and 10. However, protein concentration did not prove to be a good indicator of protein productivity. Higher grain yields for rye compensated for lower grain protein concentrations with the result that, at equal N rates, rye produced as much, or more, protein ha^{-1} than wheat in all trials except for location 2. The superior protein producing ability of rye was demonstrated in 58 percent of the trials where rye produced significantly ($P \leq .05$) more protein ha^{-1} than wheat.

Nitrogen (N) fertilizer did not have a significant ($P > .05$) influence on heading date, maturity (Table 3), hectoliter weight or kernel size (Table 4) in most trials. Where a significant ($P \leq .05$) N response was

Table 4. Average hectoliter and 1000 kernel weight of winter wheat and rye. See Table 1 fo locations.

Location	Hectoliter Weight (kg)		Kernel Weight (mg)	
	Wheat	Rye	Wheat	Rye
1	81.6*	74.3**	33.9**	24.1**
2	79.3	74.9	30.0**	22.4**
3	81.8	76.8*	31.7	23.4**
4	82.7	77.9*	37.4	27.4
5	81.9**	77.8**	34.1**	24.4**
6	82.5	74.0	36.0	18.1
7	81.7	72.9	33.3	16.4
8	77.1	74.8	31.1	25.6
9	78.8	74.0	33.9	25.9
10	77.5	72.0	32.3*	29.2*
11	76.4**	70.3**	29.8	19.4**
12	N/A	N/A	N/A	N/A
13	75.9	71.0	25.6	22.4*
14	76.7*	70.4*	28.7**	22.4**
15	79.1	71.0	38.6	34.0
16	79.8	73.4	36.5	34.0
17	78.3		25.4	
18	80.3		32.7	
19	78.5		28.7	
20	81.0	73.2	37.8	29.1
21	80.0*	71.1	32.2	28.5
22	80.0	72.6	34.2	29.0
23	78.8	71.5	31.5	28.8
24	79.1		35.4**	
25	79.0		32.9*	
26	80.2		31.1	
27	77.8		32.6**	
28	76.9		25.4	
29	76.2		25.8	
30	74.4**		22.6**	
31	78.4**		26.4**	
32	80.2		36.9	
33	77.5		36.5	
34	75.9		26.8	
35	79.3*		33.7	
36	79.4		31.6	
37	78.8		33.1	
38	74.3		25.0	
39	78.6		31.4	
40	N/A		34.7	

*,** Decreases due to increased N fertilizer rates significant at the 5 and 1 percent probability levels as tested by a F test.

detected, maximum differences were a one and two day delay in heading, a two and nine day delay in maturity, a three and three kg reduction in hectoliter weight, and a seven and nine mg reduction in seed size for wheat and rye respectively. A significant ($P \leq .05$) N response was observed more frequently for height (Table 3). In this instance the response was not directional and increases up to 25 and eight cm and reductions to nine and nine cm were observed with increased N for wheat and rye, respectively.

The addition of N fertilizer resulted in significant ($P \leq .05$) grain yield increases for winter wheat and rye in all trials except 6, 7, 11, 29 and 37. The residual soil N was exceptionally high and/or a severe late season drought was experienced at these five locations (Table 1). Increased levels of N fertilizer caused significant ($P \leq .05$) grain yield reductions for locations 6 and 11.

Nitrogen fertilization had a significant ($P \leq .05$) influence on protein concentration in 78 percent of the winter wheat (Table 6) and 90 percent of winter rye trials (Table 7). Added N had a significant ($P \leq .05$) influence on protein yield in all trials except locations 7,11,29 and 37. As previously noted these four locations had high residual soil N and/or experienced a severe late season drought that also limited grain yield responses to added N.

The above observations indicate that increased levels of N have a greater measureable effect on height, grain yield, protein concentration and protein yield than on heading date, maturity, hectoliter weight and seed size. It was also evident that response to increased N levels was not always the same for winter wheat and rye. Dissimilar height responses were indicated by a significant ($P \leq .05$) species by N fertilizer rate

Table 5. Estimated regression coefficient (MAX), maximum predicted yield (Y_{MAX}) and yield-maximizing N levels (N_{MAX}) for winter wheat and winter rye, 1974-86. MAX from equation 2. Y_{MAX} determined from equation 3 and N_{MAX} determined from equation 4 Materials and Methods.

	WINTER WHEAT				WINTER RYE			
LOCATION	MAX	Standard error	Y_{MAX} (kg grain yield ha^{-1})	N_{MAX} (kg N ha^{-1})	MAX	Standard error	Y_{MAX} (kg grain yield ha^{-1})	N_{MAX} (kg N h
1	5313	222	2947	201	8152	235	4191	194
2	5603	193	3060	205	5225	460	3057	166
3	6437	726	3371	215	6539	475	3596	180
4	8454	535	4044	236	9837	816	4750	207
5	6771	235	3490	219	8132	497	4184	194
6	5545	348	3038	204	4144	347	2568	152
7	3799	176	2303	178	3538	449	2272	143
8	6254	1039	3304	213	9854	536	4755	207
9	7797	379	3835	229	8484	440	4306	197
10	4820	153	2747	194	5387	309	3126	168
11	1588	293	1147	125	2686	305	1825	128
12	2952	147	1897	161	4323	255	2652	155
13	3198	262	2019	166	3774	320	2390	147
14	3145	173	1993	165	3339	108	2171	140
15	9621	512	4391	246	N/A	N/A	N/A	N/A
16	6167	1142	3273	212	7640	2009	4010	190
17	2663	579	1749	155				
18	2874	81	1858	160				
19	3596	218	2210	174				
20	958	106	743	101	2442	89	1689	123
21	5716	176	3103	206	9008	1047	4482	201
22	4421	478	2579	188	10918	1956	5079	214
23	6579	399	3422	217	7710	626	4035	191
24	12561	521	5159	266				
25	10288	1610	4578	251				
26	7747	1043	3819	229				
27	9903	489	4471	248				
28	2437	50	1630	150				
29	1866	37	1312	134				
30	1568	43	1135	125				
31	4937	604	2795	196				
32	26600	3649	7589	323				
33	10162	811	4543	250				
34	2195	148	1498	143				
35	8541	235	4070	236				
36	4253	279	2506	185				
37	10308	697	4583	251				
38	2912	208	1877	161				
39	5852	424	3155	208				
40	6018	559	3218	210				

Table 6. Estimated regression coefficients for protein concentration and estimated protein yield regression coefficient (MAX), maximum predicted grain protein yield (Y_{MAX}) and protein yield-maximizing N levels (N_{MAX}) for winter wheat.

Location	Protein Concentration† Regression Coefficient A	Protein Concentration† Regression Coefficient B	Regression Coefficient‡ MAX	Regression Coefficient‡ Std. Error	N_{MAX}‡ (kg N ha^{-1})	Y_{MAX}‡ (kg protein yield ha^{-1})
1	5.92	13.83	1123	50	290	436
2	4.59	19.23	945	64	276	394
3	3.65	6.87	1100	148	289	431
4	2.85	31.67	1259	120	300	464
5	3.83	11.60	1182	57	295	448
6	6.08	71.71	1079	65	287	426
7	5.90	56.16	667	39	248	318
8	4.77	23.44	1073	158	287	425
9	5.18	11.19	1813	147	329	557
10	4.26	7.53	887	39	271	280
11	11.39	3.03	379	76	204	216
12	7.27	4.78	621	21	243	304
13	5.65	1.01	804	212	263	358
14	7.99	7.02	706	67	253	330
15††	4.26	0.24	3440	1134	375	724
16	8.97	41.57	1024	311	283	413
17††	1.94	33.33	281	66	183	173
18	3.40	1.28	479	14	222	255
19††	9.90	86.21	374	22	203	214
20	5.88	0.49	170	29	150	116
21	2.75	13.62	853	34	268	371
22	8.64	26.31	656	657	247	315
23	3.71	4.14	1526	214	315	513
24	3.87	10.18	4161	730	387	771
25	2.12	15.64	1550	329	316	517
26††	9.40	60.47	882	173	271	379
27	3.40	32.27	1585	71	318	523
28	5.16	2.89	421	16	212	233
29	4.01	5.62	267	12	179	166
30	5.14	6.20	212	16	164	139
31	3.85	10.55	736	102	256	339
32††	4.01	0.52	3209#		213	887
33	3.28	6.97	2790	697	360	671
34	4.73	1.04	390	46	207	220
35	4.33	20.11	1896	236	332	569
36††	3.44	6.76	674	68	249	320
37††	3.25	11.90	1704	156	324	541
38††	2.66	14.01	375	26	204	214
39	5.91	11.18	1411	158	309	492
40††	3.10	0.10	1277	372	301	467

† Equation 1 Materials and Methods. C = 8.5 and K = 0.02302.

‡ MAX from equation 2, N_{MAX} determined from equation 4 and Y_{MAX} determined from equation 3 Materials and Methods.

†† Protein concentrations of 12.7, 8.6, 8.5, 8.0, 12.5, 10.8, 11.7, 10.5 and 11.6 were observed for locations 15,17,19,26,32,36,37,38 and 40, respectively. Increased rates of N did not produce a significant ($P \leq .05$) change in protein concentration for the N rates considered in these trials.

# For this location, least-square analyses did not produce a value for MAX when DEP = 948.8 and SLOPE = 4.9. Least-squares analysis was successful when all 3 regression coefficients were estimated for this location; SLOPE = 11.5, DEP = 587.3 and MAX = 3209.

Table 7. Estimated regression coeficients for protein concentration and estimated protein yie regression coefficient (MAX), maximum predicted grain protein yield (Y_{MAX}) and protein yield-maximizing N levels (N_{MAX}) for winter rye.

Location	Protein Concentration Regression Coefficient[†] A	B	Regression Coefficient[‡] MAX	Std. Error	N_{MAX}[‡] (kg N ha^{-1})	Y_{MAX}[‡] (kg protein yield ha^{-1})
1	4.30	32.02	1571	91	291	517
2	3.03	16.59	781	100	240	350
3	3.34	11.15	1048	133	262	417
4	2.97	38.59	1683	307	296	535
5	3.55	19.50	1433	118	285	494
6	6.62	50.23	761	68	238	345
7	7.26	39.14	676	84	229	320
8	4.27	51.89	1898	418	305	566
9	3.34	9.93	1598	46	292	522
10	5.92	6.27	1311	61	278	472
11	6.28	2.06	538	127	212	275
12	6.74	8.16	956	82	255	395
13	7.03	4.65	863	173	247	372
14	6.65	8.00	666	62	228	317
15[††]	4.40	0.52	- - - - HAIL DAMAGE - - - -	- - - -	- - -	-- -
16	1.19	39.76	855	409	246	370
20	4.76	3.09	405	16	192	226
21[††]	4.50	0.17	2696	369	328	658
22	2.85	52.96	1793	430	301	552
23	6.44	17.70	2461	701	322	634

[†] Equation 1 Materials and Methods. C = 8.0 and K = 0.02302.

[‡] MAX from equation 2, N_{MAX} determined from Equation 4 and Y_{MAX} determined from Equation 3 Materials and Methods.

[††] Protein concentrations of 12.3 and 12.4% were observed for locations 15 and 21 respectively. Increased rates of N did not produce a significant ($P \leq .05$) change in protein concentration for the N rates considered in these trials.

interaction for this character in 67 percent of the trials where comparisons could be made. Responses to N by wheat and rye were more similar for the remaining characters. The species by N fertilizer rate interaction was significant ($P \leq .05$) for heading date, maturity, seed size, hectoliter weight and yield in 0,33,25,15 and 10 percent of the trials, respectively. The species by N fertilizer rate interaction was significant ($P \leq .05$) for protein concentration and protein yield in 37 percent of the trials.

The potential for grain yield increase through the use of inorganic N fertilizer has been recognized for over a century. However, describing this response mathematically still presents a methodological challenge. Part of the difficulty in describing N response lies in the fact that fertilizer is not the only source of N available to the plant. Consequently, data from individual fertilizer trials reveal only part of the grain yield N response curve. In addition, because residual soil N varies from trial to trial, it is difficult to compare response curves from different trials unless variations in soil N supply are taken into account. Unfortunately, plant available soil N cannot be determined with precision. Soil N exists in several interacting pools that have different plant availability. The movement of N among these pools, e.g., mineralization, fixation, immobilization, etc., is influenced by environmental factors, e.g., temperature, moisture, crop residue, etc., with the result that plant available N constantly changes throughout the cropping season. Fertilizer N also enters into these complex interactions making it extremely difficult to obtain a precise measure of total plant available N. Given these limitations, available soil N, as estimated from soil tests, and fertilizer N were considered to be equally plant-available in this study (Heapy et al. 1976, Zentner and Reed 1977, France and Thornley 1984, Bole and Dubetz 1986). Total available N was calculated as the sum of available soil N plus added fertilizer N thereby allowing for the relative positioning of fertilizer N response curves for different trials.

The Mitscherlich equation has been frequently employed to describe yield responses to fertilization (Engelstad and Khasawnch 1969). Unfortunately, the Mitscherlich equation did not accommodate the yield depression found at high N levels in high stress environments in this study. Yield depression at high N levels has been frequently observed (Terman et al. 1969, Stanford and Hunter 1973, Mengel and Kirkby 1979, Caliandio et al. 1981) and becomes an important consideration in N management under the marginal moisture conditions experienced with extended rotations in semi-arid climates like that of the western Canadian prairies. Many researchers have shown a preference for polynomial equations to describe grain yield responses to N fertilizer (Mason 1956). These equations are simple to fit; however, because different fertilizer trials often sample different regions of the N response curve, the resulting equations usually take on a variety of forms. In addition, nonlinear responses in which a variable appears in a equation more than once, e.g., quadratic equations, are often difficult to interpret biologically. The inverse polynomial function outlined by France and Thornley (1984) provides another option that has been employed to describe fertilizer response. This type of equation (Equation 2) was chosen in the present study because it provided a curvilinear yield - N fertilizer response surface that conformed well with the general grain yield trends observed in the field data.

Grain yield data from fourteen winter wheat and nine winter rye fertilizer trials provided samples of the N response curve that were complete enough to allow for least square estimates of the three regression coefficients SLOPE, MAX and DEP in equation 2. Within species, SLOPE of the grain yield response curves were similar for these trials (mean SLOPE = 65.8 for wheat and 88.5 for rye). Values of the coefficient accounting for grain yield depression at high N levels (DEP) were also similar (mean DEP = 903 for wheat and 800 for rye). In the remaining trials, limitations imposed by the regions of the response curve sampled prevented least squares estimates of the regression coefficients in equation 2. Consequently, the mean values for SLOPE and DEP determined above were utilized to obtain least square estimates of the coefficient MAX (Table 5) and grain yield response equations (Figure 1 and 2) for all winter wheat and rye N fertilizer trials. Predicted grain yields from these equations explained 96 and 88 percent of the variability in actual yield for wheat and rye, respectively, indicating that they provided excellent expressions of grain yield response to N fertilization (Figure 3 and 4).

The SLOPE value in equation 2 may be considered a measure of initial N fertilizer use efficiency in grain production. This value may be influenced by both plant and soil characteristics. In this study, values for SLOPE indicate that the initial N fertilizer use efficiency in wheat grain production was only 89 percent of rye. Factors such as differences among genotypes in root feeding depth, thereby allowing plants different access to N, and/or differences in internal N use efficiency would be expected to produce differences in SLOPE. Although not factors in species comparisons in this study, variables such as N volatization,

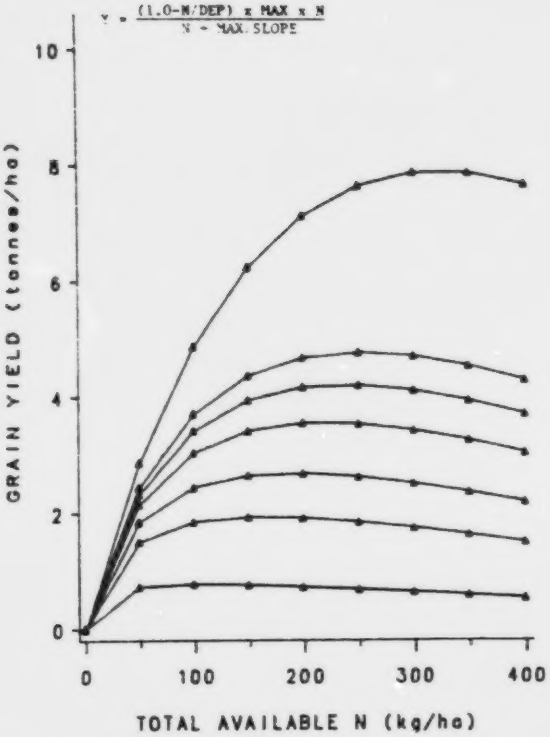

Figure 1 Relationship between grain yield and total available nitrogen for winter wheat.

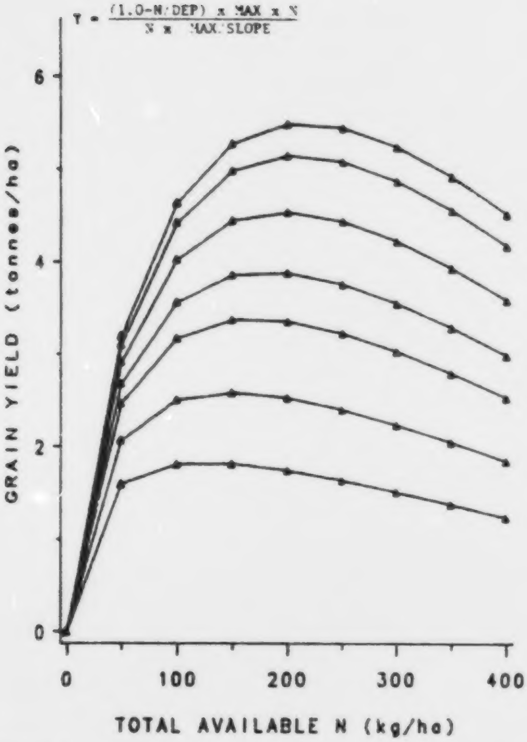

Figure 2. Relationship between grain yield and total available [illegible] for winter rye.

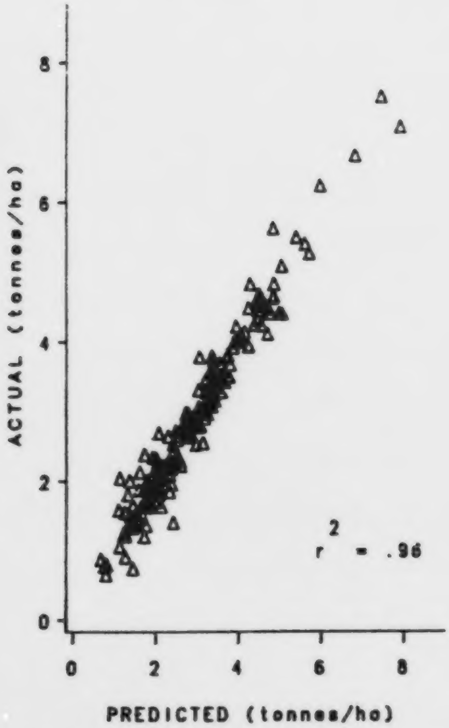

Figure 3. Predicted versus actual winter wheat grain yields.

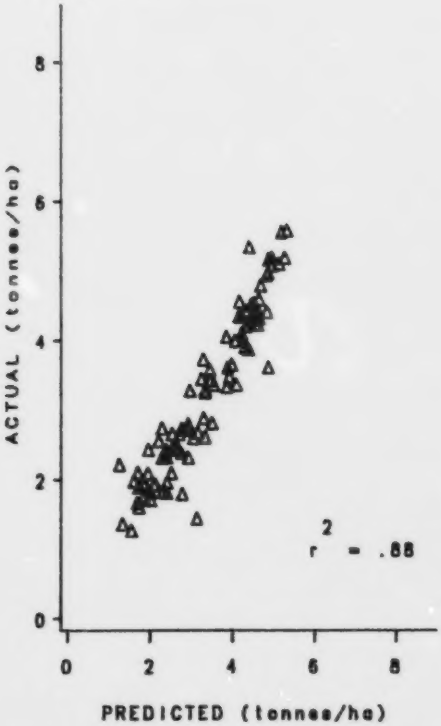

Figure 4. Predicted versus actual winter rye grain yields.

immobilization, etc., of added N fertilizer would also be expected to influence SLOPE values.

Grain yield depression from excessive N supply is often associated with luxuriant growth that results in lodging and/or increased incidence of diseases. Neither of these factors presented problems in the present study. Even at high rates of N fertilization under irrigation conditions there was no apparent lodging or increased incidence of diseases. Consequently, it appears that the grain yield depression (DEP) observed in this study was more of a physiological response to high N levels.

Grain yield increases from added N were not due to increases in the yield component seed size (Table 4). Therefore, maximum sink size was determined at or before the completion of spikelet initiation. Apparently the only adjustments to N supply to take place after this stage of development were compensation for adverse environmental conditions through tiller loss, floret abortion (blasting) and/or, as a last resort, reduced seed size.

The asymptotic maximum, or grain yield potential MAX in equation 2 accounted for most of the variability in grain yield response to N fertilizer among the trials in this study (Table 5). Within species, SLOPE and DEP were held constant in equation 2. Therefore, differences in maximum predicted grain yield (Y_{MAX}) and level of total available N at which maximum grain yield was obtained (N_{MAX}) were determined by differences in MAX (Figure 1 and 2). MAX may be influenced by both environment (Table 1) and genotype (Table 2).

The large influence of environment in determining grain yield N response was demonstrated by three- and ten-fold increases in Y_{MAX} due to locations for Puma rye and Norstar wheat, respectively (Table 5). The difficulties in predicting N requirements for maximum grain yield in this region of the American Great Plains were emphasized by the fact that these environmentally dependent increases required 1.7- and 3.2-fold increases in N (N_{MAX}) for rye and wheat, respectively. A large number of environmental factors have been shown to influence grain yield response to N fertilizer. However, on the Great Plains of North America, moisture supply is considered to be the chief factor limiting N response (Terman et al. 1969, Smika and Greb 1973). In the present study, the N responses obtained under irrigation compared to conditions of extreme drought clearly demonstrate the interdependence of N and water in determining grain yield (Table 1 and 5). In addition, the importance of moisture distribution over the growing season should not be underemphasized. Without exception, the lowest yielding trials in this study were victims of mid- or late-season droughts that would not have been predicted on the basis of spring moisture reserves.

The importance of genotypic differences in determining grain yield response to N fertilizer were also demonstrated in this study. In comparative trials, Y_{MAX} for rye averaged 25 percent more and required 10 percent less N fertilizer (N_{MAX}) than wheat (Table 5). Consequently, in addition to a greater N use efficiency, the winter rye cultivars utilized had a greater grain yield potential than the winter wheat cultivars when produced in these environments.

Considerable difficulty was experienced in describing grain yield responses to added N fertilizer. Lack of precision in estimates of residual plant-available soil N, the influence of environment in modifying the N cycle, and the fact that N fertilizer trials usually sample only part of the N response curve made it difficult to compare results from different trials. These factors also restrict our ability to obtain a clear picture of the complete N response curves for grain protein concentration and grain protein yield.

The N response curves for protein concentration were similar for winter wheat and rye. After an initial lag (lag phase), protein concentration increased rapidly (increase phase), and then tailed off at high N levels (Fig. 5 and 6). The length of the initial lag phase of the curve was reflected by the size of the B value in equation 1 (Table 6 and 7). For several locations, the lag phase extended beyond the 50 kg ha^{-1} N level (Fig. 5 and 6) with the suggestion that there may be an initial decrease in protein concentration (Bole and Dubetz 1986, Partridge and Shaykewich 1972). The presence of an initial lag phase in the protein concentration N response curve suggests that a minimum grain protein concentration exists for each species. The mean protein concentration for locations with no increase for at least the first two N levels sampled indicated that the minimum grain protein concentration was approximately 8.5 and 8.0 percent for wheat and rye, respectively. These values were employed as estimates of C in equation 1. The increase phase of the grain protein concentration N response curve was similar for both wheat and rye. Therefore, the coefficient K, that determines the rate at which grain protein concentration increases to its asymptote, was also held constant in equation 1 (Table 6 and 7). The asymptotic protein concentration achieved at high N levels (C+A in equation 1) varied among locations. Consequently, the two coefficients A and B in equation 1 were determined by least square estimates, with C and K held constant as indicated above, to give grain protein concentration N response equations for each wheat (Table 6) and rye (Table 7) fertilizer trial. Predicted grain protein concentration from these equations explained 98 and 93

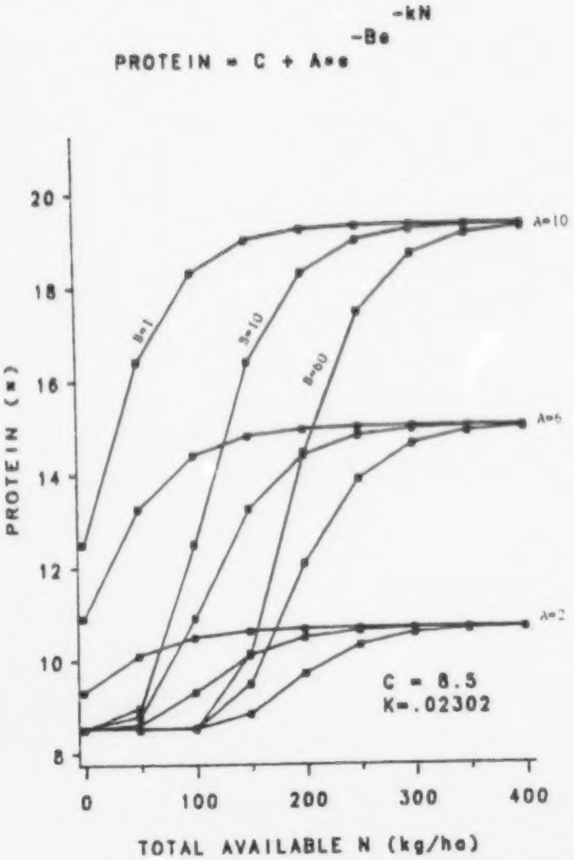

Figure 5. Relationship between protein concentration and total available nitrogen for winter wheat.

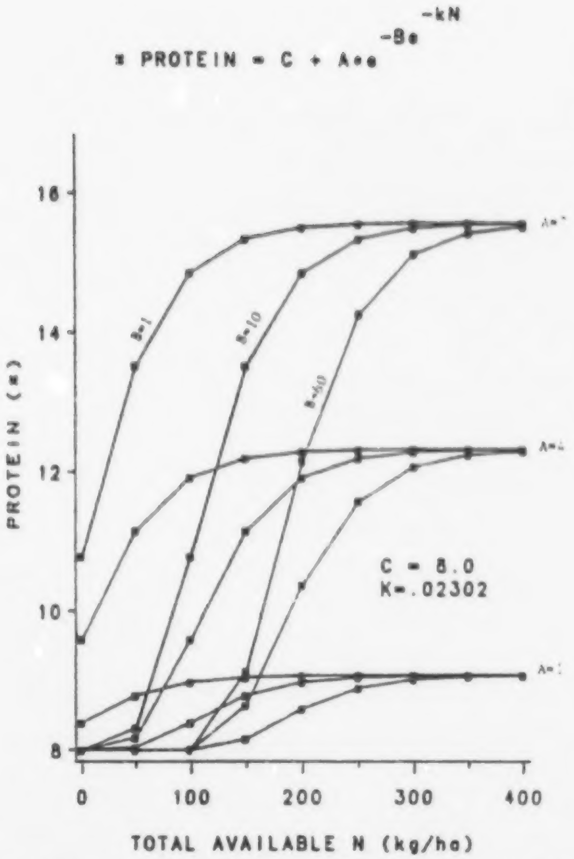

Figure 6. Relationship between protein concentration and total available nitrogen for winter rye.

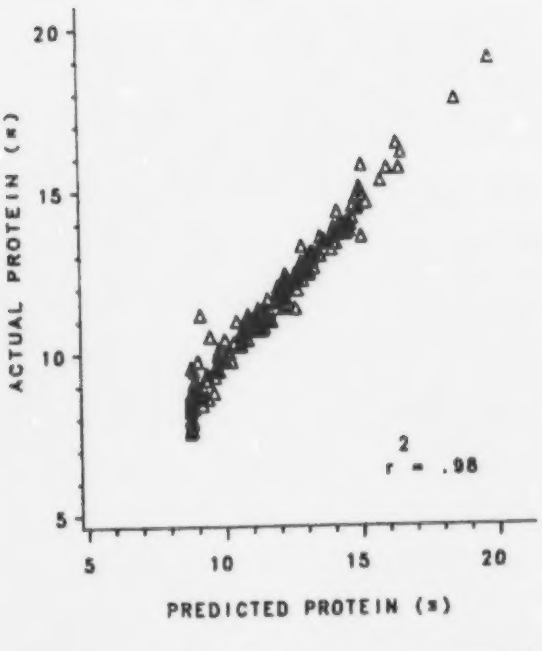

Figure 7. Predicted versus actual protein concentration for winter wheat.

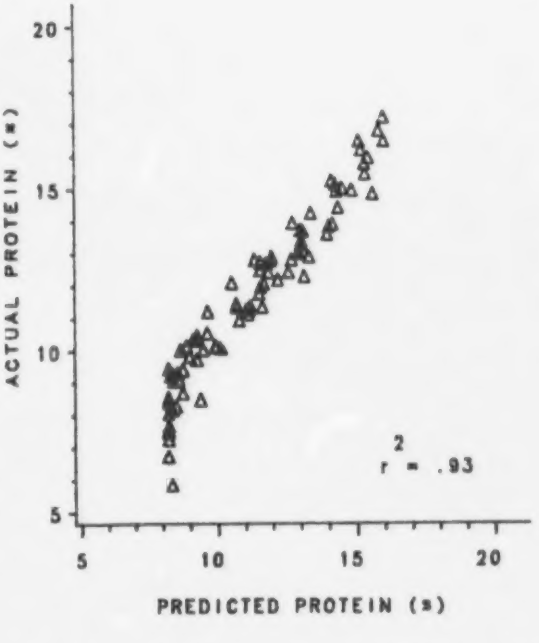

Figure 8. Predicted versus actual protein concentration for winter rye

percent of the variability in actual grain protein concentrations for wheat (Fig. 7) and rye (Fig. 8), respectively.

The above observations suggest a strong genotypic influence on minimum grain protein concentration (C) and the rate (K) at which protein concentration increases to its asymptote. In contrast, large location effects indicate that the relative length of the initial lag phase (B) and the asymptotic protein concentration achieved at high N levels (A) are both under greater environmental influence. Yield is considered to be a good measure of the cumulative influence of environment upon plant growth, i.e., the more favorable the environment the greater the yield. However, neither the asymptotic protein concentration (A) nor the relative length of the lag phase (B) were significantly ($P>.05$) correlated with maximum grain protein yield (Y_{MAX}) indicating that the response to environmental cues determining protein concentration differ from those for yield in these trials. These differences should not be completely unexpected because the periods of maximum nitrogen assimilation (prior to anthesis) and grain carbohydrate synthesis (after anthesis) are subject to different environmental emphasis during early and late plant growth stages. This change in emphasis would be expected to have a major influence on final protein concentration which is determined by the relative relationship between grain protein yield and total grain yield.

The inverse polynomial function outlined by France and Thornley (1984) provided a useful description of total grain yield response to N for these trials. The N response curve for grain protein yield took a form similar to that observed for total grain yield (Fig. 1 and 2). Consequently, the inverse polynomial function also provided a curvilinear yield - N fertilizer response surface that conformed well with the grain protein yield data for these trials. Protein yield data from seven winter wheat and four winter rye fertilizer trials provided samples of the N response curve that were complete enough to allow for least squares estimates of the three regression coefficients SLOPE, MAX and DEP in equation 2. With one exception (Table 6), SLOPE of the protein yield response curves were similar within species (mean SLOPE = 4.9 and 5.3 for wheat and rye, respectively). Values of the coefficient accounting for protein yield depression at high N levels (DEP) were also similar (mean DEP = 949 and 869 for wheat and rye, respectively). These mean values of SLOPE and DEP were utilized as constants to obtain least square estimates of the coefficient MAX, and complete protein yield response equations, for each winter wheat (Table 6, Figure 9) and rye (Table 7, Figure 10) N fertilizer trial. Predicted protein yields from these equations explained 94 and 89 percent of the variability in actual protein yield for wheat and rye, respectively (Figure 11 and 12).

The SLOPE value in equation 2 may be considered a measure of initial N fertilizer use efficiency in grain protein production. In this study, the values for SLOPE suggest that, under low available soil N levels, 86 (4.9/5.7 x 100) and 92 (5.3/5.7 x 100) percent of the initial increment of N fertilizer was recovered as grain N for wheat and rye, respectively. However, the approximate nature of these estimates is emphasized when one considers that the initial N recovery for wheat at location 32 was 202 (11.5/5.7 x 100) percent (Table 6). In this instance, it is probable that the residual soil N available to the plant was severely underestimated. The mean values for SLOPE indicate that the initial N fertilizer use efficiency in wheat grain protein production was only 92 percent of rye. As expected, this value is similar to the relative initial N use

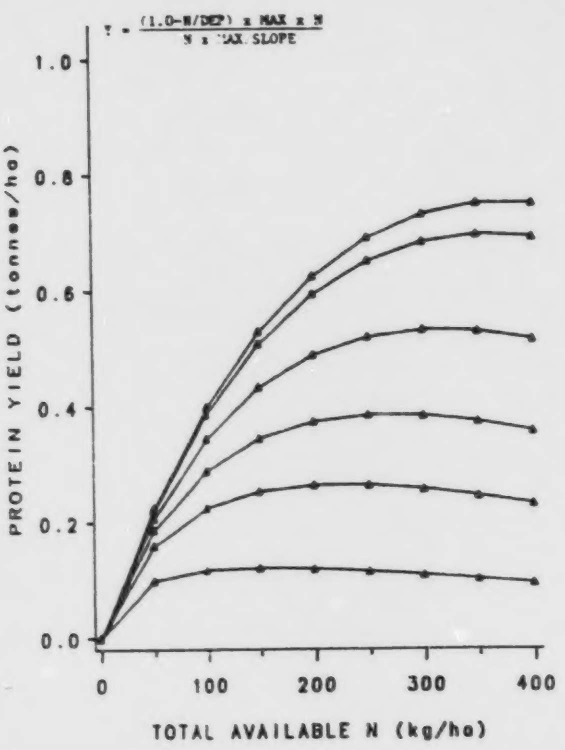

Figure 9. Relationship between protein yield and total available nitrogen for winter wheat.

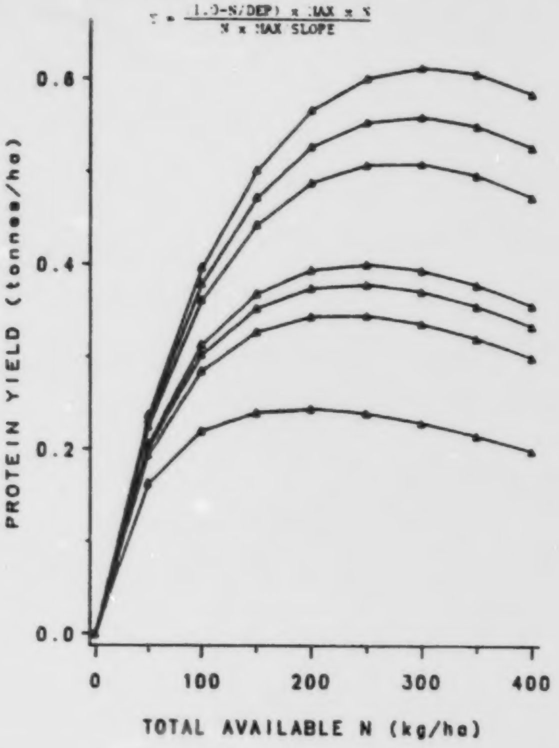

Figure 10. Relationship between protein yield and total available nitrogen for winter rye.

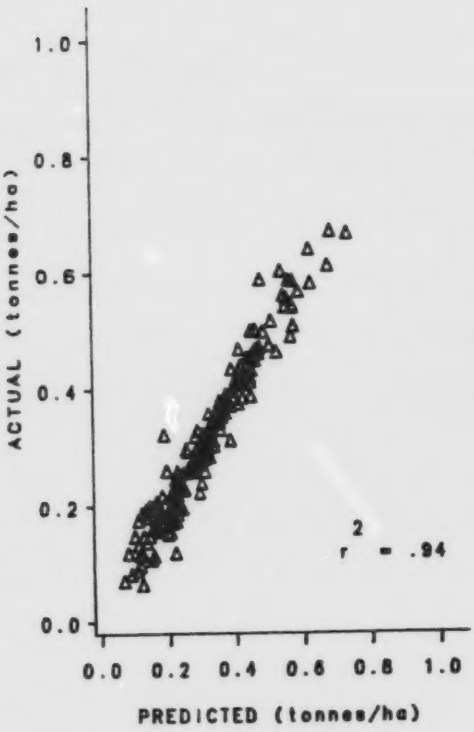

Figure 11. Predicted versus actual winter wheat grain protein yields.

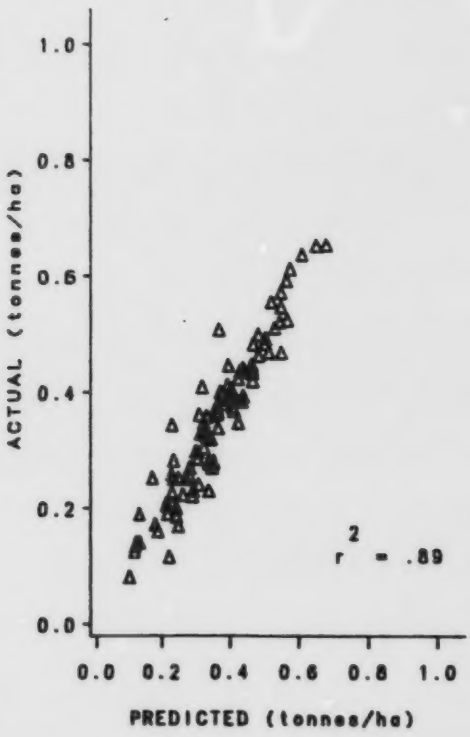

Figure 12. Predicted versus actual winter rye grain protein yields.

efficiency of 89 percent for total grain production of wheat compared to rye.

Grain yield depression was observed at high N levels in the present study. Increases in grain protein concentration at high N levels did not compensate for reductions in grain yield with the result that decreases in grain protein yield were also evident at high N levels. The absence of increased lodging and level of diseases with increased N rates suggests that the protein yield depression (DEP) was also a physiological response to high N levels.

The asymptotic maximum, or protein yield potential MAX in equation 2, accounted for most of the variability in grain protein yield response to N fertilizer among the trials in this study (Tables 6 and 7). Within species, SLOPE and DEP were held constant in equation 2. Consequently, differences in maximum predicted grain protein yield (Y_{MAX}) and level of total available N at which maximum protein yield was obtained (N_{MAX}) were determined by differences in MAX (Fig. 9 and 10). A poor relationship (r = .18 and -.25 for wheat and rye, respectively) existed between maximum protein concentration (C+A) and maximum protein yield (Y_{MAX} in Tables 6 and 7). In contrast, maximum protein yield (Tables 6 and 7) was highly dependent (r = .93** and .84** for wheat and rye respectively) upon maximum total predicted grain yield (Table 5). As a corollory to these observations, differences in total grain yield are a better indicator of difference in protein productivity than are differences in grain protein concentration.

Total grain yield N response has been shown to be highly dependent upon environmental variables. A similar large environmental dependency was observed for grain protein yield responses to N in these trials. For example, location effects accounted for 2.9 and 7.6-fold increases in

Y_{MAX} of Puma rye (Table 7) and Norstar wheat (Table 6), respectively. The difficulty in predicting N requirements in this region was once again emphasized by the fact that 1.7 and 2.6-fold increases in N were required to achieve these environmentally dependent increases in Y_{MAX} for wheat and rye grain protein yield, respectively. The large grain protein yield N response obtained under irrigation compared to conditions of extreme drought in these trials also emphasizes a strong interdependence of N and water in determining grain protein yield (Table 6).

A confounding of genotypic differences with location effects prevented a comparison of cultivars within species for this study. Between species, it has been demonstrated that rye requires 10 percent less N fertilizer to produce 25 percent greater maximum predicted total yield than wheat. The lower grain production by wheat is accompanied by a higher maximum grain protein concentration, i.e., mean values of 14.2 percent for wheat (Table 6) versus 12.8 percent for rye (Table 7) in comparable trials. However, mean maximum grain protein yield for wheat was only 87 percent of rye even though plant-available N levels for maximum grain yield were estimated to be approximately the same (mean values of 268 kg ha^{-1} for wheat and 266 kg ha^{-1} for rye). These observations lend further support to the contention that winter rye has a greater N use efficiency than winter wheat.

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were no significant differences for test weight or thousand kernel weight of the grain samples.

Patterns of dry matter production, nitrogen concentration and nitrogen uptake.

The patterns of dry matter production are illustrated in figure 1. At Perdue, Clair (1985-86) and Hagen, the amount of dry matter produced tends to increase until maturity. At the other five locations, the curves for dry matter production tend to level off by about mid-July.

Figure 2 shows the patterns of nitrogen concentration of the stems, leaves and heads. As expected, the nitrogen concentration of the stems and leaves decreased during the growing season at all sites. This resulted from an increase in dry matter, which caused a dilution of the nitrogen, and from translocation of nitrogen from the stems and leaves to the wheat heads. In 1983-84, the concentration of nitrogen in the heads remained constant from head emergence to maturity at both Clair and Kernen. At the Saskatoon and Perdue sites, nitrogen concentration of the heads tended to increase slightly while the reverse was true at the four remaining sites.

Nitrogen uptake during the growing season is illustrated by the graphs in figure 3. At most sites, the nitrogen yields tend to increase until the end of June and then remain constant or increase very slowly until harvest. The one exception is the Perdue site. At Perdue, the nitrogen uptake by the winter wheat plants tended to continue until harvest. This could be due to a larger amount of moisture in the soil since this field was fallowed in the previous season.

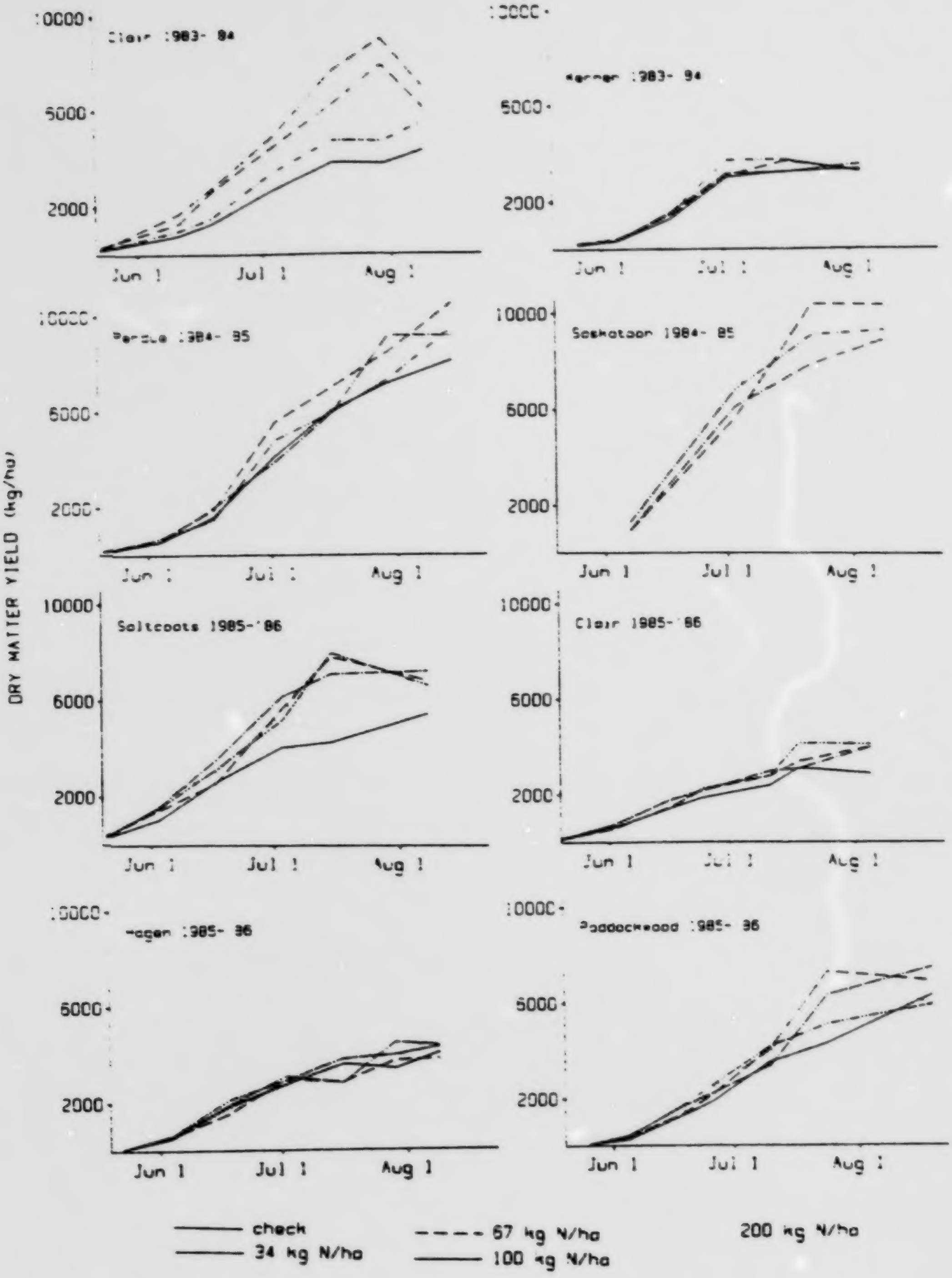

Figure 1. The patterns of dry matter production during the growing season at each site.

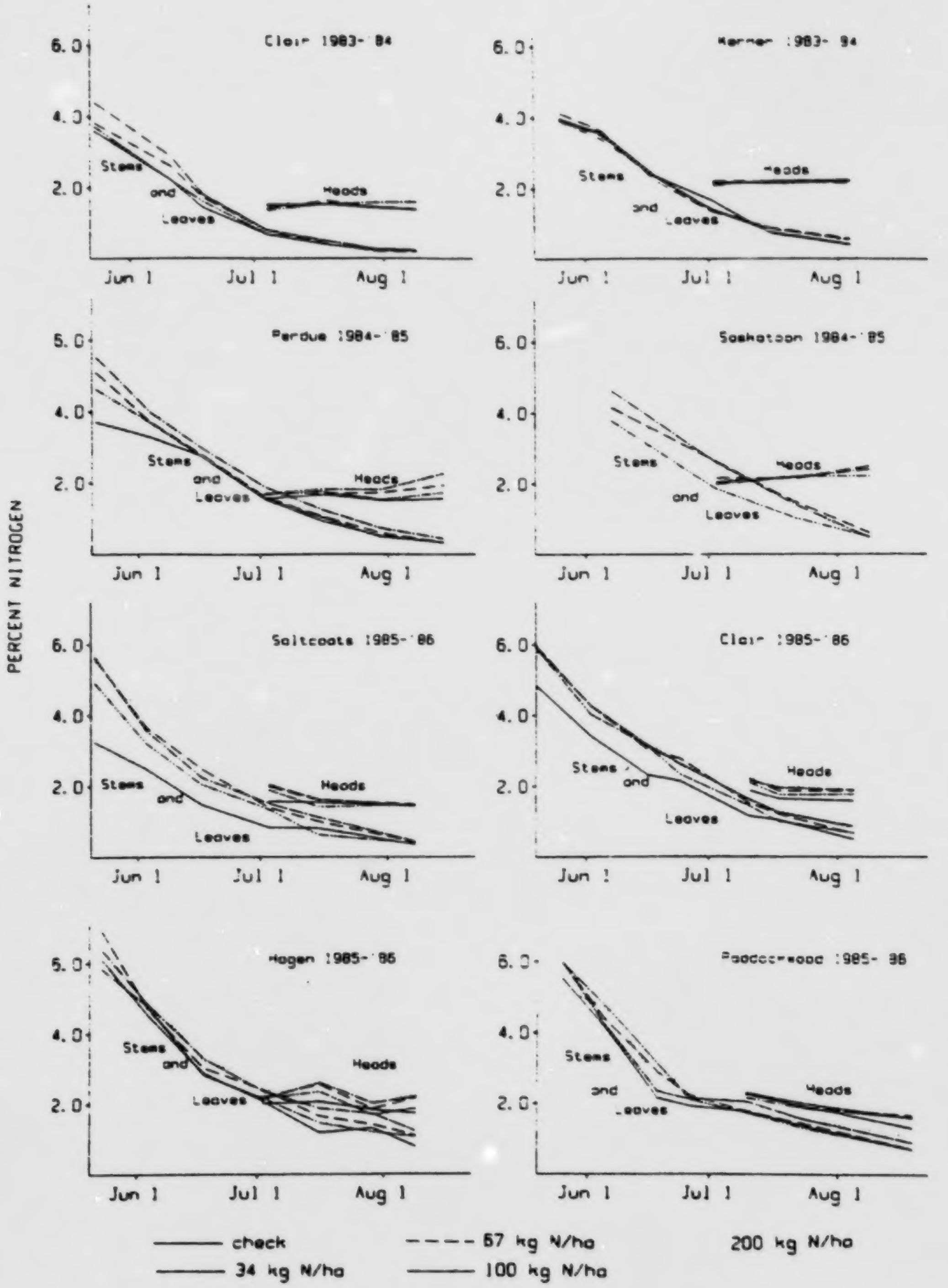

Figure 2. The patterns of plant nitrogen concentration during the growing season at each site.

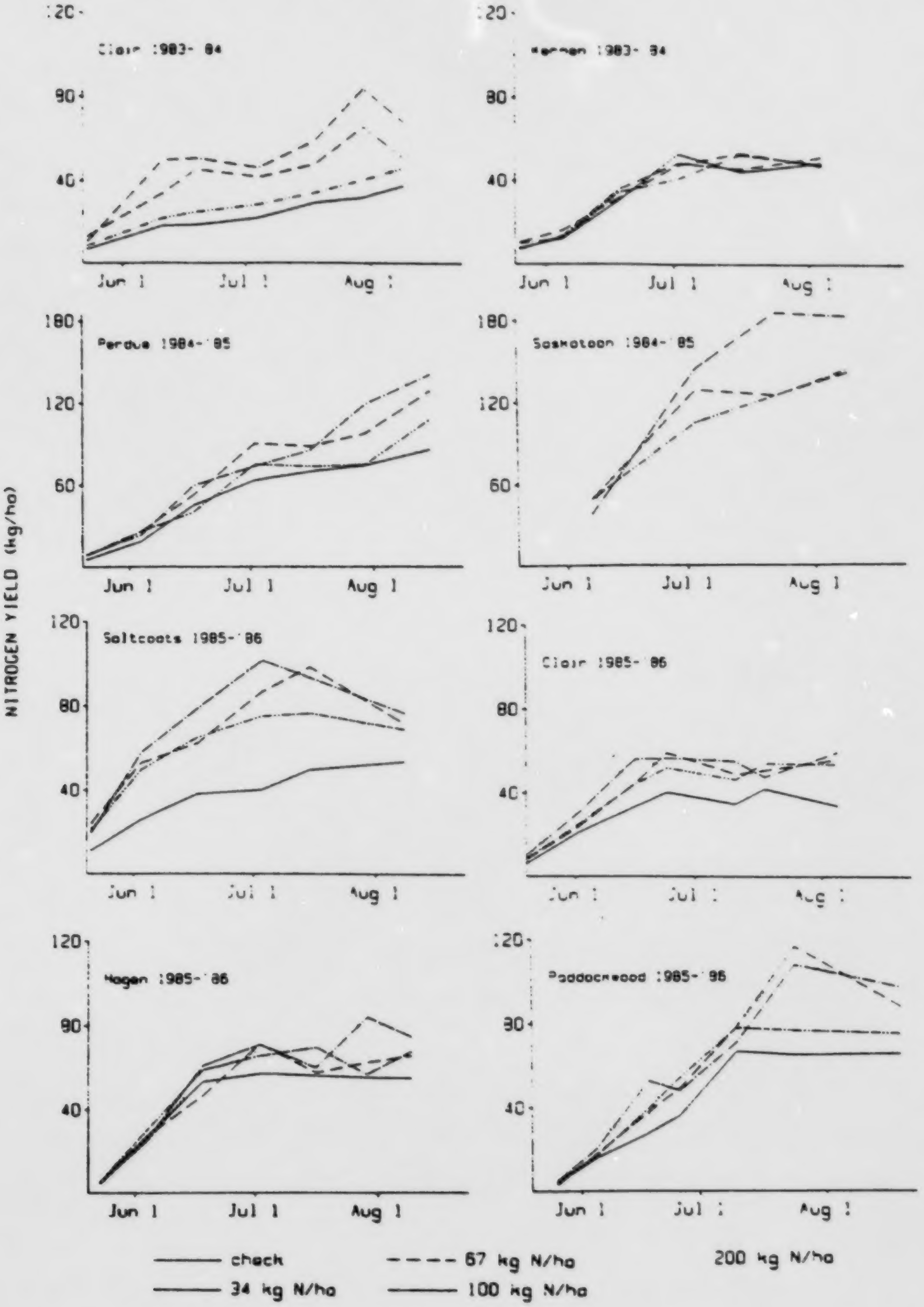

Figure 3. The patterns of nitrogen uptake during the growing season at each site.

To examine the differences in nitrogen uptake among fertilizer rates, the values for nitrogen yield were converted to a percentage of the final or harvest nitrogen yield for each date and plot. When these values were analyzed, there were no significant differences among fertilizer rates. This indicates that the pattern of nitrogen uptake does not vary with fertilizer rate. For each site, the data for nitrogen yield (as a % of final N yield) were averaged to produce a general curve for nitrogen uptake at that site. These curves for the eight locations are illustrated in Figure 4. Note that, in general, there is a rapid increase in nitrogen yield until about anthesis. After anthesis,most of the curves tend to level off and much less nitrogen was taken up until maturity.

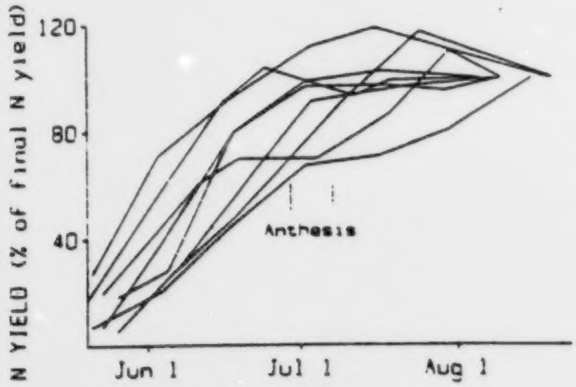

Figure 4. Patterns of nitrogen uptake at all eight locations.

Figure 5 represents a further simplification of these general uptake curves. For each stage of plant growth, the nitrogen yields of the eight sites were averaged to produce the curve found in Figure 5. Note that, on average, about 90% of the total nitrogen in the plant at harvest was already present at anthesis. This value ranged from 70% at Perdue to 106% at the Saltcoats trial.

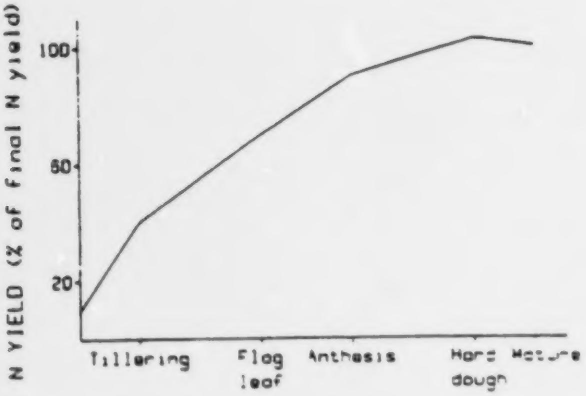

Figure 5. Average pattern of nitrogen uptake during the growing season.

DISCUSSION

Effect of fertilizer treatments.

The effect of nitrogen fertilizer rate on dry matter yields, plant nitrogen concentration and nitrogen yields varied with environmental conditions such as residual soil nitrogen and amount of rainfall received. The influence of the environment is very important (Henry et al. 1986; Spratt and Gasser, 1970). The effects of applied nitrogen on the grain had similar variations. For most locations, there were no differences in modified harvest and nitrogen indexes, indicating that there was no change in plant efficiency with a change in available nitrogen.

In general, when differences among fertilizer treatments were found during the growing season, these differences were also apparent in the grain sample. In some cases, it was possible to detect differences in the grain values that were not found in the plants during the growing season. This may be due to larger sample sizes used for harvesting grain than for collecting plant samples prior to harvest. As a result, variability in the grain samples was reduced and differences were easier to detect. Therefore, when looking for differences in nitrogen use under varying rates of fertilizer, it may be easiest to examine grain samples rather than plant samples.

Patterns of dry matter production, nitrogen concentration and nitrogen uptake.

In this study, the dry matter yields of Norstar winter wheat increased until maturity at three of the eight locations but tended to level off by mid-July for the other sites. These pattern differences may be related to soil moisture. Gregory et al. (1979) found that dry matter accumulation almost stopped four weeks before harvest. They attributed this to limited water supply and to a reduction in photosynthesis in the leaves after translocation of nutrients to the grain. Other authors have also reported a decrease or cessation of dry matter production before harvest (Gregory et al. 1981; Boatwright and Haas, 1961; Cox et al. 1985; Karlen and Whitney, 1980).

Typical patterns of plant nitrogen concentration were observed in this study. The percent nitrogen of stems and leaves decreased during the season as expected. Nitrogen concentration of the heads either decreased, increased or remained constant from head emergence until maturity, depending on environmental conditions. Johnson et al. (1967) found that grain nitrogen concentration either increased until maturity or remained constant, depending on wheat variety. Karlen and Whitney (1980) reported that nitrogen concentration of the wheat heads was fairly constant from heading until harvest. Concentration of nitrogen in wheat heads is dependent on the environment which can also influence the production and movement of carbohydrates to the grain during grain filling.

The pattern of nitrogen uptake was not affected by nitrogen fertilizer rates in this study. This is contrary to a study by Boatwright and Haas (1961) who found that unfertilized plants continued to take up nitrogen until harvest but that plants grown with added nitrogen had a maximum nitrogen yield at heading.

The general pattern of nitrogen uptake (see Figure 5) shows that the most rapid nitrogen accumulation occurred prior to anthesis. An average of 90% of the total harvest nitrogen was already present in the plants by anthesis. This is similar to a studies by Austin et al. (1977) who found an average of 83% present at anthesis and Waldren and Flowerday (1979) who observed that 80% of the total nitrogen was accumulated by grain filling. Some studies have indicated that nitrogen uptake occurs until plant maturity (Spiertz and Ellen, 1978; Spratt and Gasser, 1970). Gregory et al. (1981) found that the pattern of nitrogen uptake varied from year to year. In a dry year, very little nitrogen was taken up after anthesis, but when soil moisture levels were higher, the crop continued to accumulate nitrogen after anthesis. This supports the findings of this study which showed a general increase in nitrogen yield until harvest at one site grown on a fallow field which should contain more moisture than stubble fields.

Some loss of nitrogen from the plants prior to maturity occurred at Saltcoats, Clair (1985-86), Paddockwood, Clair (1983-84), and Kernen. Previous authors (Boatwright and Haas, 1961) have attributed the loss to sampling error, loss of plant parts or translocation to the roots. In addition, Daigger et al. (1976) suggested that these losses may be due to loss of ammonia gas or other nitrogen gases from the plant.

The results of this research have shown that under Saskatchewan conditions, most of the nitrogen accumulated by winter wheat is taken up prior to anthesis. Though differences among fertilizer rates were found for dry matter yield, plant nitrogen concentration, nitrogen yield and their corresponding values for grain, there were no differences in the pattern of nitrogen uptake during the growing season.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support of the Canada-Saskatchewan Economic Regional Development Agreement. The Canadian Wheat Board scholarship awarded to B. A. Schewe was also greatly appreciated.

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INFLUENCE OF NITROGEN RATE, FORM AND PLACEMENT ON THE ESTABLISHMENT OF NO-TILL WINTER WHEAT SEEDLINGS

A.M. Johnston and D.B. Fowler
Crop Development Centre
University of Saskatchewan

Introduction

The increased interest in the production of winter wheat in Saskatchewan has come about as a result of the crop being successfully overwintered utilizing a stubble-in or zero-till seeding technique (Fowler and Gusta, 1978). This production of the winter wheat crop on stubble results in soil nitrogen deficiencies which must be corrected if optimum yields are to be achieved. The recommended practice for correcting these nitrogen deficiencies has been the broadcast application of ammonium nitrate nitrogen fertilizer in the early spring prior to regrowth (Fowler, 1982).

The increased interest in zero-till seeding equipment for winter wheat production has resulted in the development of several seed drills capable of applying nitrogen at seeding time in a band separated from the seedrow. There is considerable producer interest in this type of specialized seeding equipment as a result of concerns that broadcast applications of nitrogen are more subject to immobilization in surface residues, that nitrogen may become stranded at the soil surface as a result of poor spring precipitation, that broadcast applications of urea nitrogen could be subject to high losses by volatilization, and the general lack of interest in handling ammonium nitrate nitrogen fertilizer by fertilizer companies. For these reasons several alternate methods of fertilizer nitrogen application to winter wheat have been investigated.

Foster and Austenson (1985) reported that highest grain yields were obtained in an experiment where nitrogen was seedplaced or sidebanded at seeding. They reported no damaging effects on seedling establishment or winter hardiness associated with the seed placement of 60 kg N/ha as either ammonium nitrate or urea.

Fowler (1986), summarizing results of 14 years of field observations of winter survival associated with N and P_2O_5 fertilizer trials, indicated that the application of high rates of seedplaced N result in a reduction in the winter survival ability of winter wheat seedlings (Table 1a). The application of recommended rates of N surface broadcast, or banded away from the seed in the fall did not influence the winter survival potential of wheat. It is interesting to note that the impact of 101 kg N/ha seedplaced, by reducing the winter survival ability of winter wheat, is similar to the effect of not correcting a phosphorus deficiency (Table 2a).

The objective of the experiment reported here was to determine the effects of nitrogen rate, form and placement on no-till winter wheat seedling establishment, seedling size as related to seedling vigor and the uptake of nitrogen in the fall of the year.

Table 1a. Effect of Phosphate Fertilizer on Winter Survival of Winter Wheat.

Phosphate added (kg/ha)	Subtract (FSI)
0	26
17	0
34	6
50	10

Fowler (1986)

Table 2a Effect of Seedplaced Nitrogen Fertilizer on Winter Survival of Winter Wheat.

Nitrogen added (kg/ha)	Subtract (FSI)
0	0
34	18
67	24
101	25

Fowler (1986)

1983 Experiment

Materials and Methods:

Norstar winter wheat seedling samples were collected from plots established at Clair, Kernen, Outlook and Paddockwood in the third week of October after fall growth had stopped. Treatments involved ammonium nitrate (AN) nitrogen fertilizer applied in the seedrow at rates of 0, 34, 67 and 101 kg N/ha. The experiment was laid out as a randomized complete block design with four replicates. Plots were seeded using a small plot hoe-press drill with 20 cm seed rows. Monoammonium phosphate fertilizer was seedplaced at a rate of 34 kg P_2O_5/ha to all plots.

Approximately 100 seedlings were collected from each plot for tissue analysis. Crowns were separated from leaves and roots, quick dried using forced air, and ground using a Udy Cyclone sample mill with a 0.5 mm screen size. The crown tissue samples were analyzed for nitrogen and phosphorus concentration by the Saskatchewan Soil Testing Laboratory using the autoanalyzer procedure outlined by Thomas et al. (1967).

Results and Discussion:

The addition of AN nitrogen in the seedrow resulted in a significant increase in crown tissue N concentration at only the Kernen site (Table 1). Phosphorus concentration was unaffected by increasing N rate at all of the test locations. This highly significant increase in crown tissue N concentration at Kernen, while phosphorus concentration remained unchanged, resulted in a significant increase in the nitrogen to phosphorus ratio. Combined analysis of the four test locations indicates results similar to those obtained for Kernen (Table 1).

The mean tissue N concentrations for each location and combined locations are listed in Table 2. It shows that at every location maximum crown tissue nitrogen was attained at the 67 kg N/ha rate, beyond which N concentration declined slightly.

Soil moisture conditions at or shortly following seeding were reported as excellent with September precipitation of 62.2 mm, 196% of the thirty year average. Detailed weather records indicate that at Saskatoon 20 mm of precipitation occurred the day immediately following seeding. This was in addition to 24 mm of precipitation which fell the first six days of September. The occurrence of these favorable soil moisture conditions at seeding resulted in no noticeable difference in either stand establishment or on winter survival.

These good soil moisture conditions in 1983, and the occurrence of 132% of the long-term September precipitation in 1982 at Saskatoon, help explain the yield results reported by Foster and Austenson (1985). It also helps to explain the lack of any apparent damage to seedling establishment or overwinter survival at the Kernen site. Soil moisture was reported as good at the other test locations and there was no evidence of any effects of nitrogen rate on seedling establishment or overwinter survival.

Table 1. Effect of seedplaced ammonium nitrate on the nitrogen and phosphorus concentration and N:P ratio of winter wheat crown tissue (1983).

Location	% N	% P	N:P Ratio
Clair	NS	NS	NS
Kernen	**	NS	*
Outlook	NS	NS	NS
Paddockwood	NS	NS	NS
Combined Sites	**	NS	*

* Significant (0.05)

** Significant (0.01)

NS Nonsignificant

Table 2. Effect of seedplaced ammonium nitrate nitrogen rate on fall winter wheat seedling mean crown tissue nitrogen concentration.

	N Rate (kg N/ha)			
Location	0	34	67	101
Clair	2.79	3.28	3.55	3.49
Kernen	3.26	3.22	3.76	3.50
Outlook	2.92	3.13	3.27	3.17
Paddockwood	3.13	3.33	3.62	3.55

1985 Experiment

Materials and Methods:

Norstar winter wheat seedlings were collected from plots established at Clair, Watrous, Perdue, Outlook and Floral after fall growth had stopped in mid-October. The experimental design used was a randomized complete block design with four replicates. Plots were seeded using a small plot disc-press drill seeding on 22 cm (9 in) centers. Ammonium nitrate nitrogen fertilizer was applied either in the seedrow or midrow banded 11.4 cm to the side and 5.0 cm (4.5 x 2.0 in) below the seedrow at seeding, at rates of 0, 45, 90 and 123 kg N/ha. Monoammonium phosphate fertilizer was seedplaced at a rate of 34 kg P_2O_5/ha to all plots.

Seedling samples were collected from an area of 0.84 m^2 representing 6 rows by 60 cm, with the sampling locations assigned within each plot at random. The samples were dried, ground and analyzed using the same procedure outlined for the 1983 experiment.

Data collected on the seedling samples prior to grinding and nutrient analysis included seedling number, sample dry weight and dry weight per 10 seedlings. Seedlings collected from the Floral site were large enough to permit separation of leaves from crowns and the collection of additional information on crown and leaf weight. Tissue sample analysis was carried out to determine seedling N and P concentration for the Clair, Watrous, Perdue and Outlook sites. At Floral N and P concentration was determined for both leaf and crown tissues.

Dry matter yield, nitrogen yield, phosphorus yield, and N:P ratio were calculated for seedlings, leaves and/or crowns. Dry matter yield was determined by multiplying sample air dry weight by a conversion factor to give kg dry matter/ha. The value for air dry weight was influenced by both seedling number and seedling weight. Nitrogen and P yield were calculated by multiplying N or P concentration by dry matter yield. Nitrogen:phosphorus ratio was determined by dividing tissue N concentration by tissue P concentration.

The graphics in the figures presented were produced using a computer graphics package capable of drawing trend lines through plotted points.

Results and Discussion:

Evaluation of the data collected in the fall of 1985 indicates two completely different types of N responses. At the Clair, Watrous, Perdue and Outlook sites soil moisture conditions at seeding were dry, as estimated by the absence of any apparent soil moisture in the surface 30 cm, while at Floral surface soil moisture was available at seeding (Table 3). September precipitation ranged from 80 to 100% of the 30-year average at those locations where data was available. These two different soil moisture conditions at seeding resulted in considerable differences in seedling development (Table 3). Seedling number, sample weight and weight per 10 seedlings were considerably lower for the Clair, Watrous, Perdue and Outlook locations when compared with Floral. For this reason the results will be presented for the Clair, Watrous, Perdue and Outlook locations combined and the Floral site alone.

1985 Combined Sites

Increasing N rate significantly reduced seedling number, weight per 10 seedlings, dry matter yield, nitrogen and phosphorus yield when nitrogen was seedplaced (Table 4). Seedling N concentration was significantly increased with increasing seedplaced N rate while seedling P concentration and seedling N:P ratio were not significantly affected. When N was midrow banded, increasing rate had no significant effect on any of the components measured. The effect of N placement is illustrated for seedling number, weight per 10 seedlings, dry matter yield, seedling N and P concentration and seedling N and P yield in Figures 1,2,3, 4 and 5, respectively. Analysis of the data with respect to the effect of N rate with the check treatments removed resulted in a nonsignificant rate effect for all components measured. This indicates that the significant response to increasing N rate with seedplaced N was as a result of the difference between the check and the nitrogen treatments for these dry sites.

Low soil moisture at seeding resulted in poor seedling establishment and development with both banded and seedplaced N treatments. A significant effect of N placement occurred only with seedling number and dry matter yield. Weight per 10 seedlings (Figure 2) was used as a means of comparing the effects of treatment on seedling size and does not reflect in any way the impact of treatment on seedling number. The occurrence of no significant difference in weight per 10 seedlings between the two nitrogen placement positions, while the effect of placement on seedling number was highly significant, indicates that seedlings that did survive to be collected must have been escapes and established out of direct contact with the seedplaced N band. This is further illustrated by the nonsignificant placement effect on tissue N concentration. Uptake of N from seedplaced N bands for those seedlings that did become established appear to have been inhibited, likely due to inadequate soil moisture to allow N movement out from the point of placement.

The absence of a significant effect of placement on nitrogen yield is a reflection of the nonsignificant response of tissue N concentration to placement while dry matter yields were significantly affected by placement.

THE PATTERN OF NITROGEN UPTAKE IN WINTER WHEAT.

B. A. Schewe and D. B. Fowler
Dept. of Crop Science and Plant Ecology and Crop Development
Center, University of Saskatchewan, Saskatoon, Sask.

ABSTRACT

The pattern of nitrogen uptake was examined in Norstar winter wheat (Triticum aestivum L.) grown at several locations in Saskatchewan during a three year period. Replicated field trials were supplemented with 0, 34, 67,100, and, in the final year, 200 kg of nitrogen per hectare applied as ammonium nitrate (34-0-0) in the early spring. Plant samples were collected at two-week intervals during the growing season and analyzed for dry matter yield, nitrogen concentration and plant nitrogen yield. Modified harvest and nitrogen harvest indexes were calculated by comparing the wheat heads to the total plant material. In general, nitrogen concentration of stems and leaves decreased during the growing season while changes in nitrogen concentration of the wheat heads were more dependent on environmental conditions. Dry matter yield and plant nitrogen yield increased during the season. This increase tended to level off near maturity at some locations, especially when moisture conditions were low. When soil nitrogen levels were low, increased amounts of nitrogen fertilizer increased dry matter yield and yield of plant nitrogen per hectare but had no effect on plant nitrogen concentration. When soil nitrogen levels were high and soil moisture was adequate, addition of nitrogen fertilizer increased only plant nitrogen concentration. At some locations, plant stand variability was too large to detect differences among fertilizer treatments. At most locations there were no differences among the fertilizer rates for harvest and nitrogen harvest indexes, indicating that there was no change in plant efficiency with a change in available nitrogen.

INTRODUCTION

Winter wheat grown on the Canadian prairies is often much lower in grain protein concentration than hard red spring wheat. If changes in the protein content of winter wheat are to be made, a better understanding of the growth and nitrogen use of the crop is necessary.

In Saskatchewan, winter wheat must be planted into standing stubble to insure winter survival of the crop. Application of nitrogen fertilizer is important since the previous crop will have depleted the soil nitrogen reserves. Most of the nitrogen used by winter wheat is required before the end of June (Fowler, 1983) but a more detailed examination of the pattern of dry matter and nitrogen accumulation is required.

Previous studies have indicated that wheat can accumulate dry matter and nitrogen until harvest (Austin et al. 1977; Spiertz and Ellen, 1978; Spratt and Gasser, 1970). However, in many cases, the uptake of nitrogen and production of dry matter decreases or stops after anthesis (Gregory et al. 1981; Karlen and Whitney, 1980; Waldren and Flowerday, 1979). Gregory et al. (1979) suggested that when uptake stopped after anthesis, it may be due to a lack of soil moisture or available soil nitrogen. In a dry year, very little nitrogen is accumulated after anthesis (Gregory et al. 1981). Boatwright and Haas (1961) found that wheat grown with little available soil nitrogen took up nitrogen until maturity but that wheat provided with sufficient nitrogen had most of its total dry weight and nitrogen by heading.

Clearly, then, the pattern of nitrogen uptake and dry matter accumulation by wheat plants varies with environmental conditions. This study was undertaken to examine the pattern of nitrogen uptake in winter wheat under varying rates of nitrogen fertilizer and Saskatchewan conditions.

MATERIALS AND METHODS

Field trials were conducted over a period of three years from 1983-1986. Norstar winter wheat treated with several rates of ammonium nitrate fertilizer (34-0-0) was grown at several locations in Saskatchewan. Plots were laid out in a randomized complete block design with four blocks. Rates of 0 (a check), 34, 67, 100, and, in the final season, 200 kg of nitrogen per ha were used. The fertilizer was broadcast on the plots in early spring.

Samples consisting of total above ground plant material were collected at approximately two week intervals from late May until harvest. When the wheat heads emerged, they were collected separately. The samples were dried, weighed and ground in preparation for analysis. Nitrogen concentration was determined using a Technicon autoanalyzer (Method #325-74W). The digestion procedure prior to analysis was similar to that described by Thomas et al. (1967). The moisture content was determined for each sample and values were reported on a dry weight basis.

At each sampling date and for each plot, the dry matter yield (kg/ha), the nitrogen concentration (%), and the plant nitrogen yield (kg of plant N /ha) were determined.

At harvest, grain yield, grain protein concentration, grain protein yield, test weight and 1000 kernel weight were determined. Values for a modified harvest index and modified nitrogen index were calculated as follows:

$$\text{Modified harvest index(MHI)} = \frac{\text{dry matter yields of heads}}{\text{total plant dry matter yield}}$$

$$\text{Modified nitrogen index(MNI)} = \frac{\text{total N in heads}}{\text{total N in whole plants}}$$

Table 1. Description of research sites.

Location	Year	Soil zone	Residual soil nitrogen (kg/ha)	Rainfall[1] (mm)
Clair	1983-84	black	29	280
Kernen	1983-84	dark brown	103	110
Perdue[2]	1984-85	dark brown	101	116
Saskatoon	1984-85	dark brown	265	147
Saltcoats	1985-86	black	76	260
Clair	1985-86	black	63	190
Hagen	1985-86	black	67	216
Paddockwood	1985-86	black	50	216

1. Amount of rainfall received during the growing season as measured at the nearest weather station.
2. The Perdue site was located on a chemically fallowed field while all of the other sites were located on stubble fields.

RESULTS

Table 1 gives a brief description of each site used during this project. All sites were located in either the dark brown or black soil zones of Saskatchewan. The residual soil nitrogen levels varied from 29 kg/ha at Clair (1983-84) to 265 kg/ha at Saskatoon. Considerable variation was also observed for the amount of rainfall received at each location during the growing season. It is also important to note that the trial located at Perdue was grown on a chemically fallowed field while all of the other trials were grown on stubble fields.

Effects of nitrogen fertilizer treatments.

Consistent significant differences among fertilizer treatments for dry matter yields were found at Clair (1983-84) and in the last half of the growing season at Saltcoats. Differences in nitrogen concentration were observed at Perdue,

Table 2. Grain yield, protein concentration and protein yield for each site.

	N fert. rate (kg/ha)	Clair 1983-84	Kernen 1983-84	Perdue 1984-85	Saskatoon 1984-85	Saltcoats 1985-86	Clair 1985-86	Hagen 1985-86	Paddockwood 1985-86
Grain yield (kg/ha)	0	2320	1681	3150	-	2851	1486	2630	1391
	34	3320	1579	3584	5353	3455	1787	2097	1942
	67	3765	1481	3802	5878	3721	1936	2044	2045
	100	4467	1600	3261	4563	3839	2180	2609	2274
	200	-	-	-	4990[1]	4082	2204	2454	2427
	$LSD_{.05}$	938	NS	NS	710.7	540.7	300.4	NS	955.7
Grain protein concentration (% dry wt.)	0	9.0	14.2	10.2	-	9.6	10.9	12.5	10.5
	34	8.0	14.6	11.1	13.4	10.0	13.2	13.6	10.4
	67	8.6	15.3	11.8	13.9	10.7	14.2	15.1	10.5
	100	8.8	15.0	12.6	14.1	10.8	15.8	15.8	12.0
	200	-	-	-	14.4	13.6	15.8	16.0	13.1
	$LSD_{.05}$	NS	0.50	0.37	0.35	1.65	1.60	2.82	2.17
Grain protein yield (kg/ha)	0	208.0	238.2	322.6	-	250.0	150.4	309.6	135.9
	34	270.2	230.9	395.2	720.1	319.0	217.1	261.5	188.4
	67	324.8	226.5	447.2	815.1	362.3	254.1	285.4	197.9
	100	392.7	239.4	410.6	644.6	381.2	321.0	377.8	254.5
	200	-	-	-	717.0	514.2	322.3	356.4	297.9
	$LSD_{.05}$	84.8	NS	60.5	NS	57.4	44.6	NS	100.8

1. At Saskatoon a rate of 135 kg/ha, not 200 kg/ha, was used.

Saltcoats, Clair (1985-86) and Hagen. Plant nitrogen yields were consistently different at Clair (1983-84) and Saltcoats. Significant differences in nitrogen yields for some dates were also observed at Perdue, Clair (1985-86) and Hagen.

In general, if soil nitrogen levels were low and rainfall was adequate, adding nitrogen fertilizer increased dry matter yields and nitrogen yields. When soil nitrogen reserves were high and rainfall was adequate, added nitrogen fertilizer increased plant nitrogen concentration and nitrogen yields. At the Saltcoats site, all three values were significantly affected by the addition of nitrogen fertilizer. At Kernen, Saskatoon, Paddockwood and most sample dates at Hagen, the rainfall was either too low or the plant stand was too variable to detect differences among fertilizer treatments.

When modified harvest and nitrogen indexes were calculated, the only significant effect occurred at Clair (1983-84) where the modified harvest index decreased when fertilizer rate was increased.

The grain yields, protein concentration and protein yields are summarized in Table 2. The Saltcoats and Clair (1985-86) sites showed significant differences among fertilizer treatments for all three values. At Kernen and Perdue, there were differences for grain protein concentration and protein yield. At Clair (1983-84), adding nitrogen fertilizer affected yield and protein yield. Differences in grain yield and protein concentration were found at Saskatoon. At Paddockwood, there were differences in grain protein yield. At all sites, there

Figure 1. 1985 COMBINED LOCATIONS
SEEDLING NUMBER

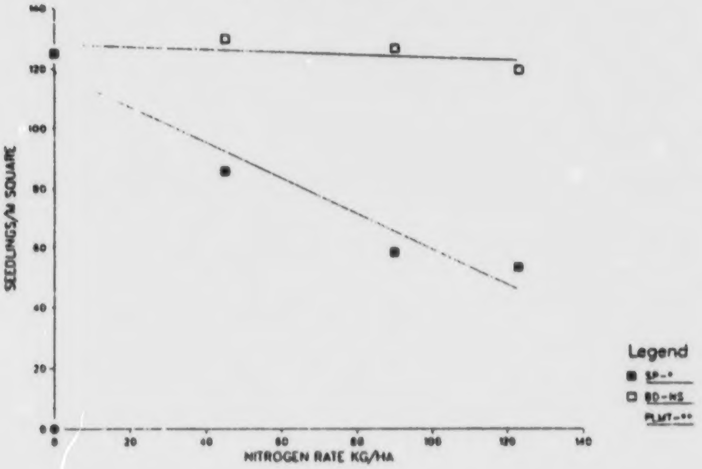


Figure 2. 1985 COMBINED LOCATIONS
WEIGHT 10 SEEDLINGS

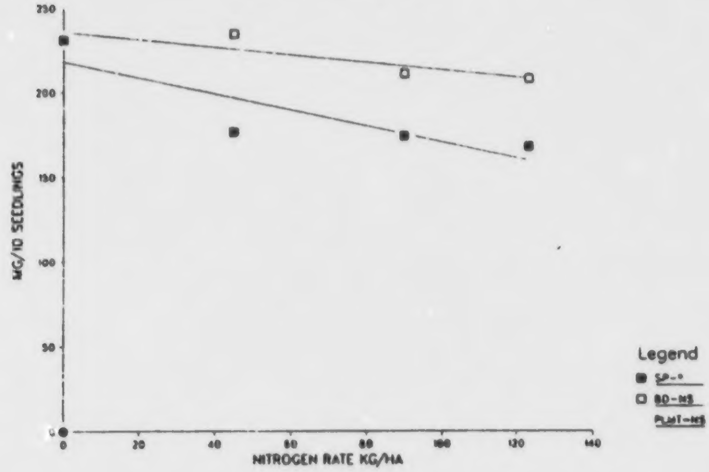
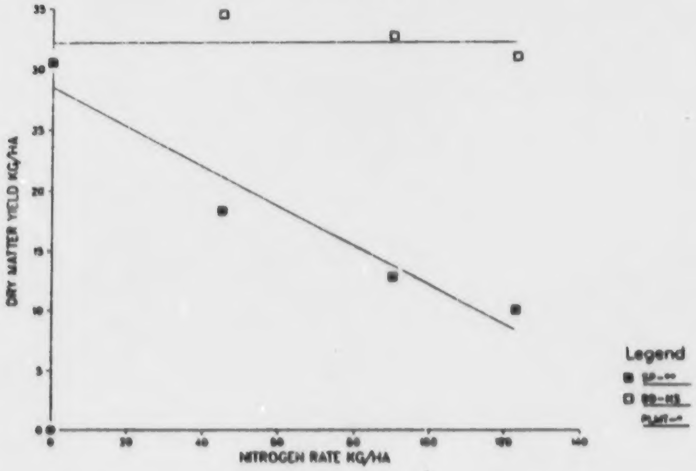


Figure 3. 1985 COMBINED LOCATIONS
DRY MATTER YIELD



1985 Floral Site

Increasing N rate had a significant effect on almost all of the variables measured when nitrogen was seedplaced (Table 5). The two variables where increasing seedplaced N rate did not result in a significant response were seedling number (Figure 6) and leaf phosphorus concentration (Figure 11). Favorable soil moisture conditions at seeding minimized the damaging effects of seedplaced N on seedling establishment. The lack of response of leaf P concentration to increasing N rate, while crown P was significantly increased by seedplaced N, appears to be a result of crown P being more closely associated with changes in crown N than leaf P is with leaf N.

Increasing seedplaced N rate resulted in a reduction of weight per 10 seedlings, dry matter yield, leaf and crown weight and N and P yield as is illustrated in Figures 7,8,9 and 10, respectively The exceptions were leaf N concentration (Figure 11), crown N and P concentration (Figure 12) and N:P ratio which all responded positively to increasing nitrogen rates.

When N fertilizer was midrow banded, increasing N rate had no significant effect on any of the variables measured with the exception of crown P concentration. Increasing the rate of midrow banded N resulted in a small but significant decline in crown P concentration (Figure 12). There appears to be a trend to increasing seedling number, weight per 10 seedlings, dry matter yield, leaf and crown weight and N yield associated with increasing the rate of midrow banded N. This type of response indicates seedling access to banded N, although not to the extent that a significant response was obtained.

A highly significant placement effect resulted for all of the variables measured with the exception leaf P concentration which was unaffected. This response was a result of seed placement of N producing a highly significant

Figure 4. 1985 COMBINED LOCATIONS
SEEDLING NITROGEN AND PHOSPHORUS CONCENTRATION

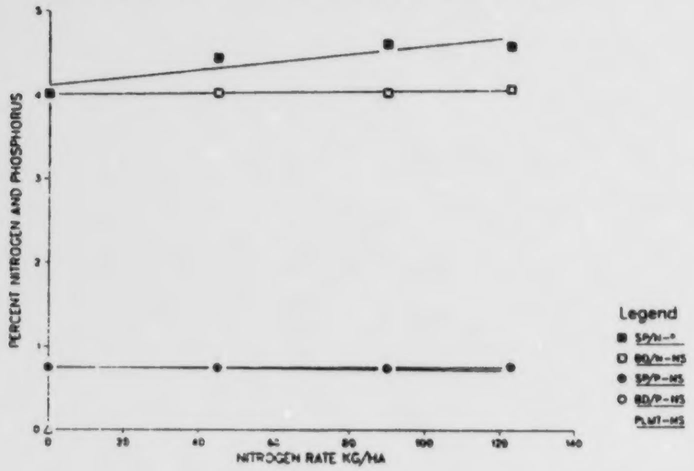


Figure 5. 1985 COMBINED LOCATIONS
SEEDLING NITROGEN AND PHOSPHORUS YIELD

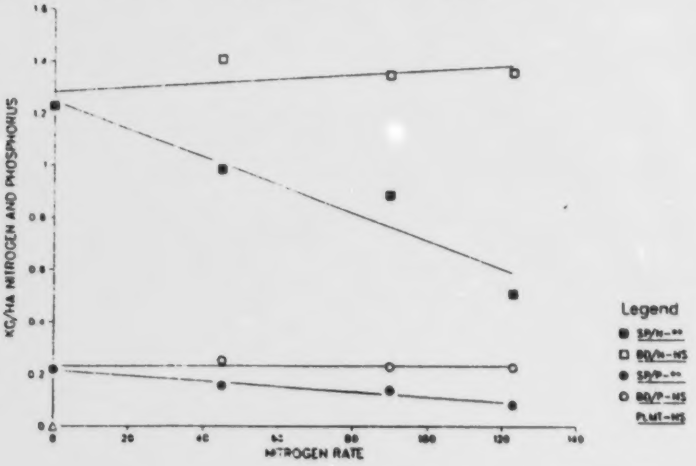
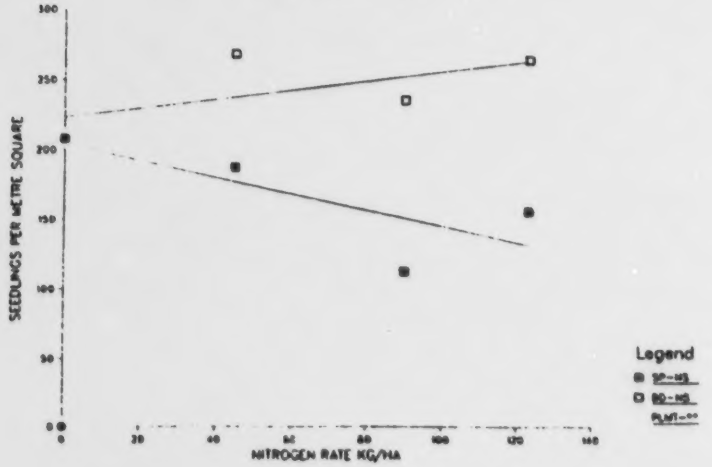


Figure 6. 1985 FLORAL
SEEDLING NUMBER



reduction in seedling number, weight per 10 seedlings, dry matter yield, N yield and P yield when compared with midrow banded N. For leaf N concentration, leaf N:P ratio, crown N concentration and crown N:P ratio, seed placement of N increased the response variable as a result of increased N availability to seedlings. There was no significant effect of placement on leaf P concentration.

A rate by placement interaction was recorded for N and P yield. As outlined previously, the calculation of N and P yield involves multiplying N and P concentration by dry matter yield. The interaction produced occurred as a result of seedplaced N causing leaf and crown weights to decrease and N and P concentrations to increase (Figure 9, 11 and 12). The opposite situation occurs for banded N treatments where leaf and crown weights increase with increasing N rate while N and P concentration decrease, reflecting the dilution effect of N and P in the larger seedlings.

Table 3. 1985 Winter wheat seedling samples:check plot means

Variable	Clair	Watrous	Perdue	Outlook	Floral
Seedling number	122	141	126	110	208
Dry matter yield (kg/ha)	31	24	32	36	142
Weight 10 seedlings (g/10 seedlings)	.204	.154	.250	.315	.564
Soil moisture at seeding*	Dry	Dry	Dry	Dry	Wet
Sept. precipitation (% L.T. Average)	85	100	-	-	80
Soil type	Black Loam	Dk.Br. Clay Loam	Dk.Br. Clay Loam	Dk.Br. Silty Loam	Dk.Br. Silty Loam

*Estimated at seeding time.

Figure 7. 1985 FLORAL WEIGHT 10 SEEDLINGS

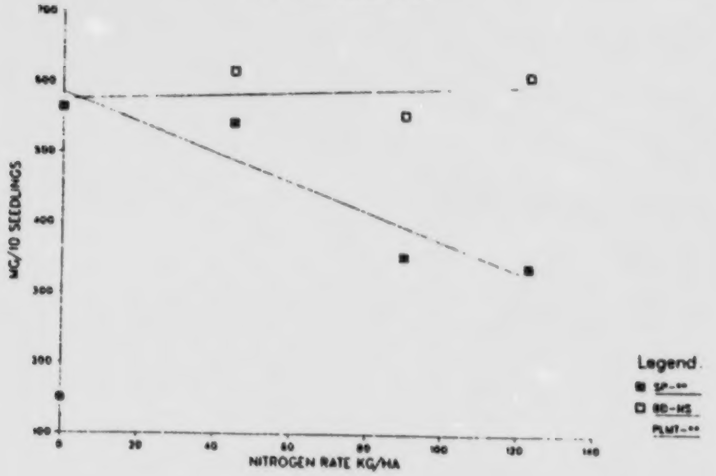


Figure 8. 1985 FLORAL DRY MATTER YIELD

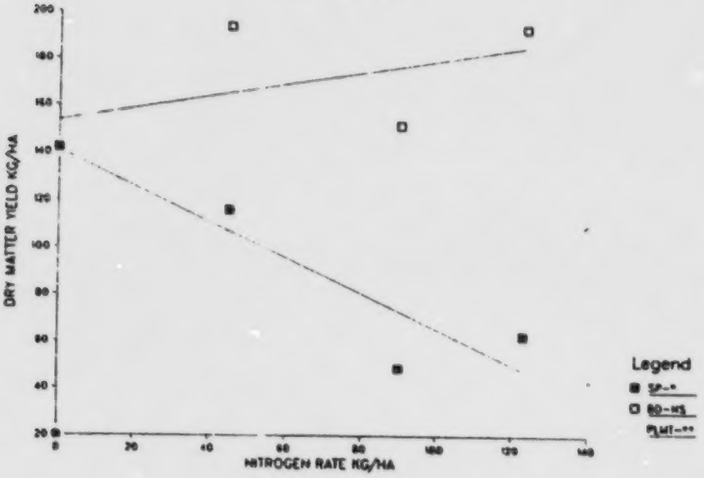


Figure 9. 1985 FLORAL LEAF AND CROWN WEIGHT

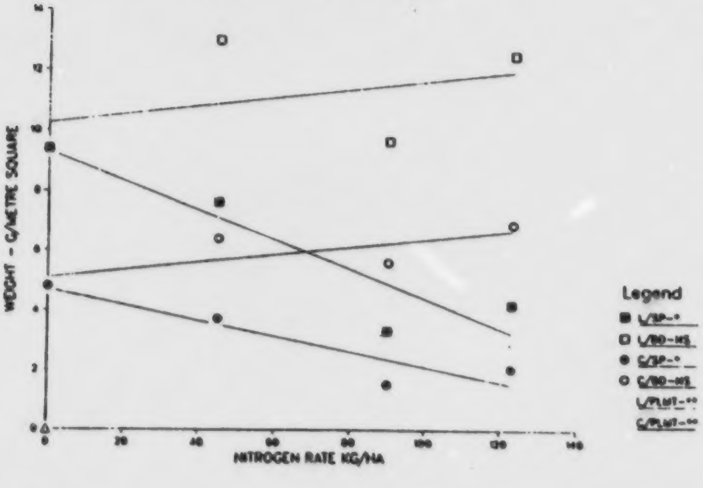


Figure 10. 1985 FLORAL NITROGEN AND PHOSPHORUS YIELD

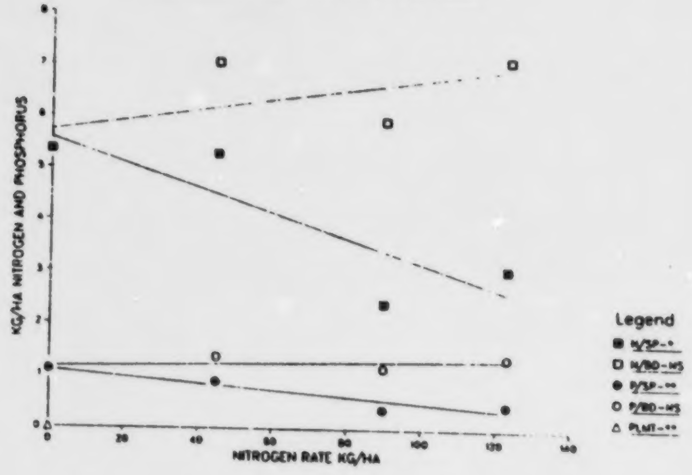


Figure 11. 1985 FLORAL LEAF NITROGEN AND PHOSPHORUS CONCENTRATION

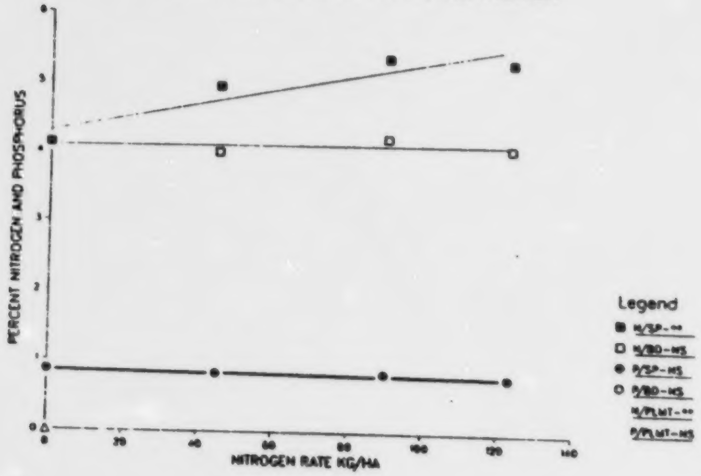


Figure 12. 1985 FLORAL CROWN NITROGEN AND PHOSPHORUS CONCENTRATION

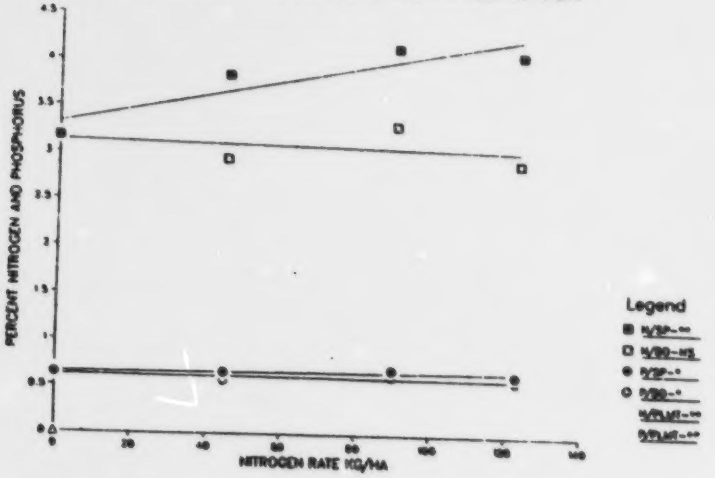


Table 4. 1985 Combined locations: level of significance of response

Variable	Rate		Placement	Rate x Placement
	SP	BD		
Seedling number	**	NS	**	NS
Weight 10 seedlings	*	NS	NS	NS
Dry matter yield	**	NS	*	NS
Seedling concentration	**	NS	NS	NS
Seedling P concentration	NS	NS	NS	NS
Seedling N:P ratio	NS	NS	NS	NS
Nitrogen yield	**	NS	NS	NS
Phosphorus yield	**	NS	NS	NS

* Significant (0.05)
** Significant (0.01)
NS Nonsignificant

Table 5. 1985 Floral location: Level of significance of response

Variable	Rate		Placement	Rate x Placement
	SP	BD		
Seedling number	NS	NS	**	NS
Weight per 10 seedlings	**	NS	**	NS
Dry matter yield	*	NS	**	NS
Leaf N concentration	**	NS	**	NS
Leaf P concentration	NS	NS	NS	NS
Leaf N:P ratio	**	NS	**	NS
Crown N concentration	**	NS	**	NS
Crown P concentration	*	*	**	NS
Crown N:P ratio	**	NS	**	NS
Nitrogen yield	*	NS	**	*
Phosphorus yield	**	NS	**	**

* Significant (0.05)
** Significant (0.01)
NS Nonsignificant

1986 Experiment

Materials and Methods

Norstar winter wheat seedlings were collected from plots established at Clair, Watrous, Kernen and Hagen after fall growth had stopped in mid-October. The experimental design used was a split-plot design with 4 replicates, the main plots being N rates and the subplots N form by placement combinations. Plots were seeded using a self-propelled small plot disc-press drill seeding on 25 cm (10 in) centers. Both ammonium nitrate (AN) and urea fertilizer were applied either in the seedrow, sidebanded at 2.5 x 2.5 cm (1 x 1 in) or sidebanded 5.0 x 5.0 cm (2 x 2 in) at seeding at rates of 0, 34, 67 and 101 kg N/ha. Monoammonium phosphate fertilizer was seedplaced at a rate of 34 kg P_2O_5/ha to all treatments.

Seedling samples were collected from an area of 0.93 m^2, representing 4 rows by 91 cm. The samples were dried, ground and analyzed using the same procedure as outlined for the 1983 experiment.

The data collected on the seedling samples was the same as that outlined for the 1985 experiment. The seedlings from the Clair and Watrous locations were separated for independent nutrient analysis of crowns and leaves while entire seedlings were analyzed for the Kernen and Hagen sites.

Results and Discussion

Soil moisture conditions at seeding ranged from poor to excellent in the fall of 1986. However, reasonably good establishment was achieved at all four test locations (Table 6). The wide range in gravimetric soil moisture measured at seeding was minimized considerably by sampling time in the third week of October. The only exception to this was the Hagen site where soil moisture was very dry at seeding and continued to be dry at sampling time. The impact of these low soil moisture conditions are reflected in the

Table 6. 1986 Winter wheat seedling samples: Check plot means

	Clair	Watrous	Kernen	Hagen
Seedling number	210	219	260	227
Air dry weight	4.27	5.53	5.04	4.81
Weight per 10 seedlings	.206	.252	.189	.211
Gravimetric Moisture				
at Seeding	21.59	18.39	14.93	11.76
at Sampling	27.78	27.68	23.43	18.15
Soil type	Yorkton loam	Weyburn clay loam	Elston clay	Blaine Lake clay loam

increased effect of N rate and N form on the variables measured.

The presentation of results will involve a discussion of each variable measured at each location. Levels of significant responses by variables are listed in Table 6 as well as illustrated in figures.

Seedling Number

Increasing N rate had a highly significant effect on seedling number at 3 of the 4 sites when N was seedplaced (Table 7, Figure 13). Increasing seedplaced N rates resulted in a decline in seedling numbers at Clair, Watrous and Hagen while there was no effect at Kernen. The nonsignificant effect of seedplaced N on seedling number at Kernen is similar to the results reported by Foster and Austenson (1985) at the same location. This response is likely attributable to the clay soil type at this location. The high cation exchange capacity of this clay soil is capable of minimizing the damaging effect of seedplaced N (Harapiak et al., 1986). Only at Watrous did increasing N rate at the 2.5 x 2.5 cm sidebanded placement have a significant effect with seedling numbers increasing as rate increased.

With the exception of Hagen there was no form (rate) effect on seedling number at any placement position. At Hagen, the dry site, there was a highly significant form (rate) effect with seedplaced urea N reducing seedling numbers to a greater degree than AN N.

Weight per 10 Seedlings

Increasing seedplaced N rate resulted in a reduction in weight per 10 seedlings at the Clair and Hagen sites (Table 7, Figure 14). At both of these locations increasing the rate of seedplaced N resulted in a reduction in 10 seedling weight. A significant form (rate) effect occurred at both of these locations with urea causing a greater reduction in weight than AN. This form (rate) effect was highly significant at Hagen where only seedplaced urea resulted in any decline in weight compared with the check.

When the N was sidebanded 2.5 x 2.5 cm there was a significant rate effect on weight per 10 seedlings at the Watrous, Kernen and Hagen sites. At all sites increasing sidebanded N rate increased the weight per 10 seedlings, indicating that sidebanding at as little as 2.5 x 2.5 cm eliminated the negative impact associated with seedplaced N. There was also a form (rate) effect at Hagen where the ammonium nitrate sidebanded at 2.5 x 2.5 cm was still producing a significantly increased 10 seedling weight compared to urea. This response is likely due to the dry conditions maintaining more of the urea in a form unavailable to plant uptake.

Dry Matter Yield

Increasing seedplaced N rate resulted in a highly significant reduction in dry matter yield at Clair, Watrous and Hagen locations (Table 7, Figure 15). As seedplaced N rates increased dry matter yield declined. There was a significant form (rate) effect at the Clair and Watrous sites and a highly significant form (rate) effect at the dry Hagen site. At all 3 locations seedplaced urea resulted in greater reductions of dry matter yield than did ammonium nitrate. At Kernen there was no significant effect of N rate or form (rate) on dry matter yield, again a reflection of the nonsignificant effect of rate or form (rate) on seedling number or 10 seedling weight associated with the clay soil type.

Sidebanded N at 2.5 x 2.5 cm resulted in a significant rate effect at Clair, Watrous and Hagen where increasing N rate increased dry matter yield relative to the check.

Leaf Nitrogen Concentration

At the Clair and Watrous sites, where leaves and crowns were separated for independent analysis, increasing N rate had a highly significant effect

Table 7. 1986 Fall Winter Wheat Seedlings:Level of Significance of Response

Variable		Clair		Watrous		Kernen		Hagen	
		Rate	Form(Rate)	Rate	Form(Rate)	Rate	Form(Rate)	Rate	Form(Rate)
Seedling number	A[1]	**	NS	**	NS	NS	NS	**	**
	B[2]	NS	NS	*	NS	NS	NS	NS	NS
	C[3]	NS	NS	NS	NS	NS	NS	NS	NS
Weight 10 seedlings	A	**	*	NS	**	NS	NS	**	**
	B	NS	NS	**	NS	*	NS	*	*
	C	NS	NS	NS	NS	NS	NS	NS	NS
Dry matter yield	A	**	*	**	*	NS	NS	**	**
	B	*	NS	**	NS	NS	NS	*	NS
	C	NS	NS	NS	NS	NS	NS	NS	NS
Leaf N concentration	A	**	NS	**	NS				
	B	**	NS	**	NS				
	C	*	NS	**	NS				
Leaf P concentration	A	NS	NS	*	NS				
	B	NS	NS	*	NS				
	C	NS	NS	NS	NS				
Leaf N:P ratio	A	**	NS	**	NS				
	B	*	NS	**	NS				
	C	*	NS	**	NS				
Crown N concentration	A	**	NS	NS	NS				
	B	*	NS	NS	NS				
	C	NS	NS	NS	NS				
Crown P concentration	A	NS	NS	NS	NS				
	B	NS	NS	NS	NS				
	C	NS	NS	NS	NS				
Crown N:P ratio	A	**	*	NS	NS				
	B	*	NS	NS	NS				
	C	NS	NS	NS	NS				
Seedling N concentration	A					**	NS	**	**
	B					**	NS	**	NS
	C					**	NS	**	NS
Seedling P concentration	A					NS	**	NS	**
	B					NS	NS	NS	NS
	C					NS	NS	NS	NS
Seedling N:P ratio	A					**	**	**	**
	B					**	NS	**	NS
	C					**	NS	*	NS
Total N yield	A	**	*	NS	NS	NS	NS	**	**
	B	**	NS	**	NS	**	NS	**	*
	C	NS	NS	*	NS	*	NS	NS	NS
Total P yield	A	**	*	**	NS	NS	NS	**	**
	B	**	NS	**	NS	NS	NS	*	NS
	C	NS	NS	NS	NS	NS	NS	NS	NS

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[1] A represents seedplaced Nitrogen.

[2] B represents nitrogen sidebanded 2.5 x 2.5 cm.

[3] C represents nitrogen sidebanded 5.0 x 5.0 cm.

*:Significant (0.05); **:Significant (0.01); NS: Nonsignificant.

on leaf N concentration at all 3 placement positions (Table 7, Figure 16). Increasing N rate resulted in increasing leaf N concentrations with seed placement>sidebanded 2.5 x 2.5 cm>sidebanded 5.0 x 5.0 cm. There was no significant form (rate) effect at either location. This response indicates access of seedlings to the applied N at all placement positions.

Leaf Phosphorus Concentration

Only at the Watrous site did N rate have an effect on leaf P concentration with both seedplaced and sidebanded 2.5 x 2.5 cm placement (Table 7, Figure 16). Increasing N rate resulted in a decrease in leaf P at both placement positions while leaf N concentration increased.

Leaf Nitrogen:Phosphorus Ratio

Nitrogen rate had a significant effect on increasing the leaf N:P ratio at all 3 N placement positions at both Clair and Watrous (Table 7, Figure 18). This increase in leaf N:P ratio is a result of increasing leaf N concentration with increasing N rate while leaf P was either unaffected or reduced (Watrous).

Crown Nitrogen and Phosphorus Concentration

Crown N concentration was increased significantly at the Clair site only when N rate was increased and when N was seedplaced or banded 2.5 x 2.5 cm (Table 7, Figure 17). There was no effect of N rate on crown N at Watrous. This variable effect of N rate on crown N, while leaf N was highly significant increased at all placements, indicates that winter wheat seedling leaves act as a sink for the bulk of the N taken up in the fall of the year. This is important since leaves play no role in winterhardiness. It's also important to note that fall developed leaves die over winter and new leaves develop the following spring resulting in a temporary immobilization of a small amount of nitrogen that was taken up in the leaves.

There was no significant effect of N rate or N form (rate) on crown P concentration at any of the placement positions at either site.

Crown Nitrogen:Phosphorus Ratio

Nitrogen rate had a significant effect on crown N:P ratio at Clair for both the seedplaced and sidebanded 2.5 x 2.5 cm treatments (Table 7, Figure 18). Increasing N rate resulted in an increase in N:P ratio. These two responses correspond with the responses obtained for crown N concentration. There was also a form (rate) effect of seedplaced N on crown N:P ratio at Clair. At all rates, urea resulted in a higher N:P ratio than did AN. Although not significant, crown N concentration was always higher with urea than AN at Clair. The opposite was true at Watrous where crown N concentration was usually always lower for urea than AN. Although only speculative at this time the increased crown N associated with urea at the Clair site may be as a result of the good seeding soil moisture conditions improving access of the seedlings to the higher levels of ammonium nitrogen associated with the urea. It has been demonstrated (Leyshon et al., 1980) that increased production is possible when nitrogen is maintained in the NH_4- form.

Seedling N Concentration

At the Kernen and Hagen sites entire seedlings were analyzed for N and P concentration. Increasing N rate resulted in a highly significant increase in seedling tissue N concentration at all placement positions at both sites (Table 7, Figure 19). This indicates that seedlings were accessing the N at all placement positions. At Hagen there was a highly significant form (rate) effect when N was seedplaced. This resulted in tissue N concentrations higher for AN than urea at all rates and indicates that at the drier Hagen site less of the urea N was available to the seedlings.

Seedling Phosphorus Concentration

At both the Kernen and Hagen sites, seedling P concentration was unaffected by N rate (Table 7, Figure 19). However, N form (rate) produced a highly significant effect at both locations when N was seedplaced. The effect of form (rate) was lower seedling P concentration with urea at all rates. This is a reflection of the lower uptake of N which occurred with seedplaced urea at both sites, although not significant at Kernen. The reduced uptake of N resulted in a corresponding lower uptake of P.

Seedling Nitrogen:Phosphorus Ratio

Increasing N rate had a significant effect of increasing seedling N:P ratio at all placements at both Kernen and Hagen (Table 7, Figure 20). These responses occur as a result of increasing N rate increasing seedling N concentration while seedling P concentration remained unaffected. The significant form (rate) effect for seedplaced N is also a reflection of the response obtained with seedling P concentration where seedplaced urea reduced seedling P concentration.

Total Nitrogen Yield

Increasing seedplaced N rate resulted in a decline in N yield at the Clair and Hagen locations (Table 6, Figure 21). This was accompanied by a form (rate) effect where urea produced a lower N yield than AN at all rates. The effect of urea was small but significant at Clair, however, it was highly significant at the dry Hagen site where increasing urea N rate resulted in a dramatic reduction in N yield.

When sidebanded 2.5 x 2.5 cm there was a N rate effect on total N yield at all locations. As N rate increased total N yield increased when the N was sidebanded. Only at the Hagen site was there a form (rate) effect as a result of lower N yields when urea was sidebanded. Again this is an indication of the reduced availability of the urea N at the drier location.

There was a small but significant rate response on total N yield at Watrous and Kernen when the N was sidebanded 5.0 x 5.0 cm. It is interesting that at both of these locations there was no significant effect of N rate on total N yield when N was seedplaced, but a significant effect when it was banded. This response to banded N, along with the nonsignificant effect of seedplaced N on weight per 10 seedlings at both sites (Table 7), is an indication that seed placement of N did not have the same impact on seedling stand establishment as occurred at the Clair and Hagen sites. This response was likely due to the soil type as both the Watrous and Kernen soils have a higher clay content with high cation exchange capacity which is capable of minimizing the effects of seedplaced N. Although the Hagen site also has a high soil clay content this could not completely compensate for the very low soil moisture conditions.

Total Phosphorus Yield

Increasing N rate had an effect on total P yield when N was seedplaced or sidebanded 2.5 x 2.5 cm at the Clair, Watrous and Hagen locations (Table 7, Figure 21). Total P yield declined with seedplaced N rates and were increased by sidebanding. At Clair and Hagen there were significant effects of form (rate) on P by yield when H was seedplaced with total P yield lower for AN than urea. The lack of many significant responses of N rate on P concentration and highly significant effects of N rate on total P yield are an indication that the differences are due more to the effects of dry matter yield rather than P concentration.

Summary and Conclusions

Although there was considerable variability over the 3 years this experiment was carried out, the data collected does indicate some common trends.

1. Seedplacement of nitrogen fertilizer resulted in reduced seedling establishment and seedling size. The only exceptions to this were associated with high clay content soils where the impact of the seedplaced nitrogen was minimized by high cation exchange capacities and where soil moisture at seeding and post-seeding precipitation were above normal. Long-term results would tend to indicate that soil moisture at seeding of winter wheat is usually low and stand establishment damage would be expected with seedplaced nitrogen.

2. When banded in the seedrow, urea had a greater negative effect on seedling establishment and seedling size than did ammonium nitrate.

3. Separation of the nitrogen fertilizer band as little as 2.5 cm (1 in) from the seedrow prevented any damage to seedling establishment and seedling size, and in most cases increased seedling size.

4. Increasing nitrogen rate had little or no effect on phosphorus uptake, resulting in an increased N:P ratio in seedling tissue.

5. Under favorable soil moisture conditions at seeding, nitrogen uptake occurred from bands placed as far as 11.4 cm (4.5 in) from the seedrow.

6. Soil moisture at seeding influenced seedling response to nitrogen rate, form and placement to a greater degree than did postseeding precipitation. Good soil moisture at seeding reduced the impact of seedplaced nitrogen treatments and positively enhanced the effects of sidebanded nitrogen on seedling development. Seeding into dry soil with seedplaced nitrogen tended to increase the damaging effects of the nitrogen when precipitation does

finally occur.

7. If nitrogen is going to be sidebanded in the fall it should be placed a minimum of 5.0 cm from the seedrow to eliminate any damaging effects on stand establishment.

Acknowledgement

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EFFECT OF SEEDING DEPTH ON THE PERFORMANCE OF WINTER WHEAT

G.E. Hultgreen, D.B. Fowler and B.A. Collins

Saskatchewan Wheat Pool, Product Development Section, Watrous, Sask. and Crop Development Centre, University of Saskatchewan, Saskatoon, Sask.

INTRODUCTION

Shallow seeding has been recognized as an important management factor in the production of winter wheat. Recent research reported by Lafond and Fowler (1986) has shown that small increases in seeding depth can have a significant effect on the emergence of winter wheat. In addition, cooler mean ambient temperatures, associated with seeding later than the optimum date, increase the differences due to the seeding depth. Poor emergence and establishment mean that seedlings do not have enough time prior to winter to accumulate sufficient energy reserves in the crown tissue. Insufficient crown development often results in reduced winter survival, poor weed competition, late maturity and low yields. The objective of these studies was to determine the effect of seeding depth on the emergence, establishment and yield of a "stubbled in" winter wheat crop.

MATERIALS AND METHODS

This report outlines the experiments seeded in the fall of 1984, 1985 and 1986. In the fall of 1984, seeding depth trials were seeded at Watrous and Outlook on Aug. 29 and Sept. 2 respectively. In the fall of 1985 and 1986 the number of sites were increased to include Watrous, Carlyle, Clair, Porcupine Plain and Saskatoon. Seeding dates in the fall of 1985 were Aug.

29 at Watrous, Sept. 11 at Carlyle, Sept. 14 at Clair, Sept. 17 at P. Plain and Sept. 26 at Saskatoon. In the fall of 1986, seeding dates were Aug. 27 at Watrous, Aug. 30 at P. Plain, Sept. 3 at Clair, Sept. 6 at Saskatoon and Sept. 10 at Carlyle.

A randomized complete block design with four replications was used for these experiments. Norstar winter wheat was direct seeded into stubble at all locations using an Edwards HD912 hoedrill in the fall of 1984 and an Edwards HD812 hoedrill in the fall of 1985 and 1986. Standard hoe openers were used on the drill for all sites. Seeding rate was 80 kg/ha with seed placed P205 @ 29 kg/ha. Nitrogen fertilizer was broadcast in spring at soil test recommendations and post-emergent herbicides were applied as required. Seeding depths of 2 cm, 5 cm and 8 cm were attempted in fall 1984 and fall 1985. In the fall of 1986 six depths were attempted starting at very shallow and moving down 0.5 to 1 cm per treatment.

Plots at all sites (except Watrous 1984) were sampled prior to freeze-up. Sampling included plant counts per unit area and x[1] whole plant samples per plot for measurement of seeding depth (as determined by the distance between the seed and the initial appearance of stem tissue chlorphyll), Haun scale, primary leaf length and oven dry weight.

Plots were harvested using a Kincaid or Hege small plot combine.

[1] X = number of plants sampled per plot

RESULTS AND DISCUSSION

1984-85 RESULTS

Table 1. Average emergence from three seeding depths at Outlook. Measurements made on plants sampled on Oct. 13, 1984.

Location	Depth (cm)	Emergence (plants/m2)	
Outlook	4.4	115	(100%)
	6.4	36	(31%)
	8.0	5	(4%)

Dry conditions at Outlook delayed germination of the seed until after a Sept. 15 rainfall. Actual seeding depth, as determined from plant measurements, was deeper than intended at the shallow 2 cm target depth (Table 1). The difference in actual seed depth compared to intended seed depth (2,4 and 8 cm) appeared to be due to soil "cave-in" into the furrow row. Differences in emergence due to seeding depth were highly significant. The delay in germination caused by dry soil at seeding was also a probable factor in the reduced emergence of the plants at the deeper seed placements.

Unusual fall and winter weather conditions in 1984-85 resulted in severe winter injury to the winter wheat crop. The plots at Watrous were 100% winterkilled and some winter injury occurred at the Outlook site. As a result, data is available from the Outlook site only.

Table 2. Effect of seed depth on yield at Outlook, 1984-85.

Location	Depth (cm)	Yield (kg/ha)	
Outlook	4.4	1810	(100%)
	6.4	1497	(83%)
	8.0	386	(21%)

Precipitation at the Outlook site was much below normal during the growing season. The dry growing conditions combined with sandy soil texture required the addition of 25 mm of irrigation water to alleviate the severe drought stress. The total growing season rainfall plus irrigation did not bring the total available water up to the thirty year average precipitation.

Yield differences due to seeding depth were highly significant with the shallow depth yielding almost five times as much as the deep depth (Table 2). Yield differences were not as dramatic as the emergence differences which indicates the ability of the plant to partially compensate for a low plant population by tillering.

The dramatic emergence and yield differences obtained in this experiment are not likely typical, however, the data indicates the significant effect that seeding depth can have on the emergence and yield of winter wheat.

1985-86 RESULTS

Soil conditions at seeding time were very dry at Watrous; very wet at Carlyle; and moist at Clair, Porcupine Plain and Saskatoon. The means for the shallow, intermediate and deep seeding depths were as follows: 3.0 cm, 4.1 cm and 6.4 cm. Intended seeding depths were 2 cm, 5 cm and 8 cm. Soil "cave-in" was the reason for the deeper than intended shallow depth of seeding treatment. The depth of the deep treatment was limited by the tendency of the V shaped packer to follow the opener into the furrow and limit effective seed depth.

Table 3. Average emergence from three seeding depths. Measurements made on plants sampled in late October, 1985.

Location	Depth (cm)	Emergence (plants/m2)	
Watrous	3.6	216	(100%)
	4.7	166	(77%)
	6.7	105	(49%)
Carlyle	2.8	258	(100%)
	3.2	189	(74%)
	5.8	252	(98%)
Clair	3.1	221	(100%)
	3.5	287	(130%)
	5.8	158	(72%)
P. Plain	3.0	208	(100%)
	5.0	139	(67%)
	7.4	115	(55%)
Saskatoon	2.5	242	(100%)
	3.9	127	(53%)
	7.0	12	(5%)
Means	3.0	229	(100%)
	4.1	182	(80%)
	6.4	128	(56%)

The first seeding date was August 31 and the last seeding date was Sept. 26. As a result, the differences in emergence due to seeding depths was exaggerated at the later seeding dates due to cooler ambient temperatures (Table 3). Saskatoon and Porcupine Plain had the greatest differences in emergence due to the interaction of cool ambient temperatures and seeding depth. At Clair there was an increase in emergence between the shallow and intermediate seed depths which could indicate that small differences in seed depth may not be as critical at earlier seed dates. When the combined means from the five sites are calculated, the medium and deep seeded treatments had a reduction in emergence of 20% and 44% compared to the shallow seeded treatment. The reduction in emergence of 20% occurred with a measured seeding depth difference of only one cm. This points out the critical importance of shallow seeding depth and the large effect that small differences in seeding depth can have on the emergence of the winter wheat seedlings.

Table 4. Effect of seed depth on yield, 1985-86.

Location	Depth (cm)	Yield (kg/ha)	
Watrous	3.6	1032	(100%)
	4.7	954	(92%)
	6.7	749	(73%)
Carlyle	2.8	3535	(100%)
	3.2	3512	(99%)
	5.8	3598	(102%)
Clair	3.1	2334	(100%)
	3.5	2227	(95%)
	5.8	1624	(70%)
P. Plain	3.0	2115	(100%)
	5.0	1753	(83%)
	7.4	1031	(49%)
Means	3.1	2254	(100%)
	4.1	2112	(94%)
	6.4	1751	(78%)

Severe winterkill occurred at Saskatoon resulting in the loss of that site. The late seeding date at Saskatoon was a probable cause of the extensive winter injury. Some winterkill also occurred at Watrous, however the other three sites were not effected by winter injury. The winter injury at Watrous resulted in weed problems at that site.

A lack of precipitation, especially during June, caused a reduction in yields at Watrous, Clair and P. Plain (Table 4). At Watrous severe stem rust further reduced yields and resulted in

15 g/1000 kernel weights. Rust did not cause yield reductions at any of the other locations. Excellent moisture conditions at Carlyle, throughout the 1986 growing season, resulted in high yields at that location. The rust epidemic which effected central Saskatchewan did not arrive in Carlyle until the crop was past the critical stage and therefore did not effect yield. Later seeded crops in the Carlyle area did suffer yield reductions due to stem rust.

Volunteer barley was a problem at the P. Plain site which required additional cleaning to arrive at the net yields. The barley problem at this site would have been less severe if the seeding date for the winter wheat would have been closer to the optimum date.

When the data from the four sites were combined, there were highly significant differences in yield due to the differences in seeding depth. On average, a 1 cm increase in seeding depth from (3.1 cm to 4.1 cm) resulted in a six percent yield reduction and a 3.4 cm increase in seeding depth (from 3.1 cm to 6.5 cm) resulted in a yield reduction of 22%. The location by seeding depth interaction for the combined analysis was also highly significant for yield. On an individual site basis, yield differences were highly significant at Clair; significant at P. Plain and not significant at Carlyle and Watrous (Table 4). The differences were not significant at Carlyle due to optimum seeding date which resulted in only small differences in plant emergence in the fall of 1985. Differences in yield at Watrous were not significant due to variable winter injury among the plots.

The 1985-86 results clearly indicate the importance of shallow seeding for best emergence and maximum yields.

1986-87 RESULTS

Soil moisture conditions were adequate for germination and emergence at Watrous, Clair, and P. Plain. The Carlyle site was dry and the Saskatoon site was very dry. Adequate precipitation occurred shortly after seeding at both Carlyle and Saskatoon and ensured good germination and emergence at these sites.

The six treatment depths were grouped into three depths by combining similar depth treatments (Table 5). This allows the results to be compared to the previous two year's data. The combined means for the shallow, intermediate and deep seeding depths were as follows: 1.9 cm, 3.5 cm and 5.1 cm. The depth of the deep seed treatment was limited by the tendency of the V shaped packer wheel to follow the opener into the furrow and limit effective seed depth.

Table 5. Average emergence from three seeding depths. Measurements made on plants sampled in late October, 1986.

Location	Depth (cm)	Emergence (plants/m2)	
Watrous	1.6	182	(100%)
	3.0	119	(65%)
	4.7	86	(47%)
Carlyle	1.8	198	(100%)
	3.3	197	(99%)
	5.7	177	(89%)
Clair	2.2	198	(100%)
	3.6	187	(94%)
	4.7	192	(97%)
P. Plain	1.9	186	(100%)
	3.8	191	(103%)
	5.1	167	(90%)
Saskatoon	2.3	224	(100%)
	3.7	202	(90%)
	5.5	185	(83%)
Means	1.9	198	(100%)
	3.5	179	(90%)
	5.1	162	(82%)

Differences in emergence were not significant at all sites except Watrous where the emergence differences were highly significant (Table 5). However, when the data from the five sites were combined, differences in emergence were highly significant.

When the means from the five sites were combined, the medium and deep seeded treatments had a reduction in emergence of 10% and 18% compared to the shallow seeded treatment. The 10% reduction in emergence occurred with a depth difference of 1.6 cm and the 18% reduction occurred with a depth increase of 3.2 cm. The differences in emergence due to depth are less than occurred in 1985-86 and are likely due the earlier seeding dates and better conditions for germination that occurred in fall 1986.

Conclusions

Significant differences in plant emergence/m2 due to seeding depth occurred in each of the three years of this study. Relatively small differences in seeding depth resulted in large differences in plant emergence especially under conditions of late seeding date or delayed germination due to dry soil conditions.

Reductions in emergence, due to increased seed depth, resulted in significantly reduced yields in the fall of 1984 and 1985, although the yield reductions were proportionately less than the reduction in emergence.

The data from these experiments indicates that shallow seeding depths result in higher plant emergence and greater yield when compared to deeper seeding depths.

REFERENCES

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ACKNOWLEDGEMENTS

Financial support from Agriculture Canada through the Canada - Saskatchewan Economic Regional Development Agreement (E.R.D.A.) is gratefully acknowledged.

THE EFFECT OF HOE-OPENER DESIGN ON DRAFT FORCES OF A MINIMUM TILLAGE HOE DRILL

B.A. Collins[1], D.B. Fowler[1] and G.E. Hultgreen[2]

[1]Crop Development Centre
University of Saskatchewan, Saskatoon,

and

[2]Saskatchewan Wheat Pool
Product Development Farm, Watrous

Introduction

Minimum tillage practices that promote soil and water conservation have become accepted alternatives to conventional summerfallow in western Canada. However, in addition to maintaining the productivity of soils, grain producers have been forced to become increasingly concerned with ways of reducing their input costs in order to survive the present cost-price squeeze in agriculture. Proper implement adjustment and operation speed are two areas that influence both production costs and soil conservation.

Seeding is the only tillage operation directly associated with the production of "stubbled-in" or "zero-tilled" winter wheat (Fowler 1983). Dry, untilled, trash covered seedbeds are very hard to penetrate and drills equipped with hoe openers or knives have been popular choices for this production system. The objective of this study was to determine the effect of seeding depth and opener design on the draft (horizontal component of pull imposed on the tractor drawbar by the implement being pulled) and power requirements of a minimum tillage hoe drill utilized for stubbling-in winter wheat.

MATERIALS AND METHODS

An Edwards HD812 four rank hoe drill with eight inch row spacing was used in all trials (Fig. 5). Draft measurements were made for five depths and three speeds using four types of openers and four different number of openers.

Draft was measured using a bonded strain gauge load cell. This S-shaped force transducer has a capacity of 20,000 lbs. with a 200 percent safe overload. The unit is fully environmentally protected against moisture ingression and by design is insensitive to barometric effects. The load cell was placed between the tractor drawbar and the hitch of the hoe drill. A metal shroud was placed around the load cell for extra protection. A Western Scale DF2000 digital weight indicator was located inside the tractor cab enabling the operator to view the draft values with ease (Fig. 6). Data was directly transcribed from the digital indicator onto a cassette recorder.

The tests were carried out in Watrous, Saskatchewan on a Weyburn clay-loam soil which has a bulk density of 0.04 lb/in^3 (1.10 g/cm^3). Soil moisture content was approximately 20.9 percent on a volume basis. Standing wheat stubble with a medium to light trash cover was present for all trials.

Seeding depths were 0.4, 0.8, 1.2, 1.6, and 2.0 inches. Seeding depths were measured as the distance seeds were placed below the soil surface in the furrow rather than the distance to the bottom of the furrow. Speeds of 4, 5 and 6 mph were chosen because they reflected normal seeding speeds. The four types of openers used were the (1) IHC Hoe, (2) Edwards Hoe, (3) Acra-Plant knife and, (4) Versatile knife (Fig. 1 to 4). The relationship between the number of openers and draft was investigated using four, six, eight and ten openers. When opener numbers were reduced, they were removed from each side of the drill symmetrically to maintain the eight inch row spacing.

A minimum of twenty draft measurements were made for each treatment comparison. Analyses of variance were conducted to determine the effects of the different parameters on draft.

RESULTS AND DISCUSSION

Effect of Opener Type

Figure 7 shows the relationship between draft and seeding depth for four types of openers in trials which had ten openers pulled at a speed of five mph. There was a significant ($P<0.001$) linear increase in draft as seeding depth increased for all openers. The four types of openers responded differently to increasing opener depth. These differences relate to the physical shape of each opener.

The IHC Hoe (shoe) opener (Fig. 1) has a broad surface area which cuts through the soil. However, the shoe is curved such that soil is able to roll up and off the shoe as it travels forward. The Edwards Hoe opener (Fig. 2) is quite blunt and does not roll the soil over. The Acra-Plant knife opener (Fig. 3) has a narrow streamlined shape. The replaceable tip is equipped with side fins which allow soil to be raised up and away from the knife as it moves through the soil. Like the Acra-Plant, the Versatile knife opener (Fig. 4) is also narrow, however, it lacks the fins on the sides of the replaceable tip. Thus, rather than lifting the soil in a rolling motion, the Versatile forces the soil to flow around the knife.

It is evident from Fig. 7 that at shallow depths the two knife openers (Acra-Plant and Versatile, denoted with a "K" in Fig. 7) have lower draft values because of their narrow, streamlined shape. The two hoe openers (Edwards and IHC, denoted with an "H") have large draft forces at shallow depths because of their broader cutting face.

As depth increases, draft of the two hoe openers also increases. The rate of draft increase for these two openers (Fig. 7) is very similar indicating that they react similarly when they are subjected to a change in depth. However, in all cases the IHC openers showed an increase in draft of approximately 150 lbs more than the Edwards openers.

The Acra-Plant knife had the lowest draft forces under almost the entire depth range. The reason for the low draft values, in comparison to other openers, is due to its physical shape. Since the soil is being uplifted by this knife, there is less shear force on the sides of the knife and thus a lower draft force results.

The Versatile opener follows an interesting pattern. Since the shear force on this knife is much higher than that of the Acra-Plant, the draft increases with depth at a much higher rate. At shallow depths, the Versatile has low draft forces because it is narrower than the two hoe openers.

The power curve (Fig. 8) follows the same pattern as draft (Fig. 7) because power is related only to draft and speed such that:

$$P = \frac{Dr \times S}{375} \qquad (1)$$

where P = Power (Hp)

Dr = Draft Force (lbs)

S = Speed (MPH)

375 = Conversion Constant

Figures 7 and 8 include regression equations and coefficients for the various lines in terms of both depth and speed such that:

$$Dr = X_1 - X_2 \times D - X_3 \times S \qquad (2)$$

where Dr = Draft Force (lbs)

D = Depth (inches)

S = Speed (MPH)

X_i = Regression Coefficients

Effect of Speed

Fig. 9 shows draft versus depth at three different speeds for an average number of openers. It is evident from Fig. 9 that speed has only a small impact on draft force, as no large differences between the three speeds at a given depth were observed. The slopes of the three lines are similar indicating that speed has little or no effect on draft, regardless of the depth at which the opener is pulled.

The relationship between power and depth is shown in Fig. 10. As previously mentioned (equation 1), power is directly related to both draft and speed. The percentage increase in power requirements for the openers, due to an increase in speed from four to six miles per hour at 0.4 in depth, is seventy-six percent. The percentage increase in draft under the same conditions (Fig. 9) is only seventeen percent. Thus, speed has a much larger effect on power requirements, than on draft.

Depth has a major effect on both draft and power. When depth is increased from 0.4 in to 2.0 in at a constant speed of five miles per hour, draft and power both increase by one hundred and twenty percent.

Effect of Number of Openers

The relationship between draft and speed is shown for the four different number of openers in Figure 11. This graph exemplifies how number of openers has a direct effect on draft. Each time two openers were added to the drill, draft increased by approximately one hundred and fifty pounds. Again speed is shown to have a minimal effect on draft.

The power curves in Fig. 12 show that when speed increases from four to six miles per hour at an average depth for ten openers, the power increased by eighty-two percent. Draft increased by twenty one percent under the same conditions.

Tractor Sizing

The Prairie Agricultural Machinery Institute makes use of the following mathematical expression to determine tractor size requirements (P.A.M.I. 1984):

$$\text{TRACTOR SIZE} = \frac{\text{DRAFT(lbs)} \times 5280\ (\frac{\text{ft.}}{\text{mile}}) \times \text{SPEED}\ (\frac{\text{miles}}{\text{hr}})}{60\ (\frac{\text{min}}{\text{hr}}) \times 33000\ (\frac{\text{ft.lbs}}{\text{min}})} \times \text{T.E.} \times \text{L.F.} \qquad (3)$$

where T.E. =Tractive Efficiency factor of either 1.25 representing a tractive efficiency of 80% on hard soils (heavy primary tillage) or 1.44 representing a tractive efficiency of 70% on loose soils (light primary tillage and all secondary tillage).

L.F. = Tractor load factor (L.F. = 1.25 representing a tractor operating at 80% of maximum pto output).

Table 1. Tractor size required to pull an Edwards HD812 with two types of openers at two depths.[1]

Type	Number	Depth (inches)	Speed (mph)	Draft (lbs)	Tractor Size (Hp)
IHC(H)	10	0.5	5	920	19.2
ACRA-Plant(K)	10	0.5	5	645	13.5
IHC(H)	10	2.0	5	2020	42.0
ACRA-PLANT(K)	10	2.0	5	1388	29.0

[1] A tractive efficiency of 1.25 was used because of the presence of standing stubble (primary tillage).

When the draft and speed values observed in the present study are entered into the Tractor Size equation (3) it can be demonstrated that, at a seeding depth of one-half inch, the horsepower requirements for the Acra-Plant knife are forty percent lower than those of the IHC Hoe (Table 1). When seeding depth increases from one-half inch to two inches, tractor size requirements for both openers more than doubles.

In addition to large reductions in power requirements (Table 1), there is also an added bonus to the winter wheat producer with shallow seeding. The probability of a successful winter wheat harvest increases significantly if the crop is sown shallow (Lafond and Fowler 1986, Hultgreen _et al_ 1987). Lafond and Fowler (1986) observed a delayed emergence in winter wheat of between three to five days, depending on temperature, due to an increase in seeding depth from one-half inch to two inches. Hultgreen _et al_ (1987) found a direct relationship between seeding depth and yield of winter wheat. In this instance, when seeding depth was increased from one to two inches there was a drop in yield of seventeen percent.

Soil Disturbance

The physical shape of opener has a major effect on soil and stubble disturbance. Both the Versatile and Acra-Plant knife openers had quite low soil disturbance. This is due largely to the fact that they are knife openers, and are thus relatively thin in width. In contrast, the IHC and Edwards Hoe openers have a larger leading surface area, resulting in more soil disturbance. No relationship between soil disturbance and draft was found during these tests.

Conclusions

Depth of seeding has a major effect on draft. Power is also greatly affected by seeding depth.

Speed has only a small effect on draft forces. However, power requirements are directly related to the speed at which the implement is being pulled and can be lowered by decreasing speed.

Increasing the number of openers caused a constant increase in both draft and power.

The physical shape of each opener plays a large role in determining draft characteristics. The Acra Plant knife is a narrow opener with fins located on the sides of the tip. Since the knife is narrow, the draft at shallow depths is low. Because of the fins on the sides of the tip, the soil is lifted as the knife moves forward. If the soil is lifted as well as pushed to the sides of the openers, the draft force is less than if the soil is not lifted. Thus, at deeper depths the Acra-Plant opener has a lower draft force than the Versatile opener because the Versatile opener does not have the fins on the knife tip.

Openers which have broad fronts tend to have moderately high draft forces at shallow depths (e.g. IHC and Edwards Hoe openers). As these openers are placed deeper into the soil, their draft increases at a rate determined by the amount of soil that is either uplifted to the surface or forced to the sides. Opener type influences power requirements for seeding.

Opener types that have higher power requirements for similar seed placement will result in higher input costs.

Seeding winter wheat at deep depths translates into higher input costs in terms of power requirements, slower emergence and lower yields.

ACKNOWLEDGEMENTS:

The authors gratefully acknowledge the financial support from Agriculture Canada through the Canada-Saskatchewan Economic Regional Development Agreement (ERDA).

XI

Fig. 1 IHC HOE OPENER

Fig. 2 EDWARDS HOE OPENER

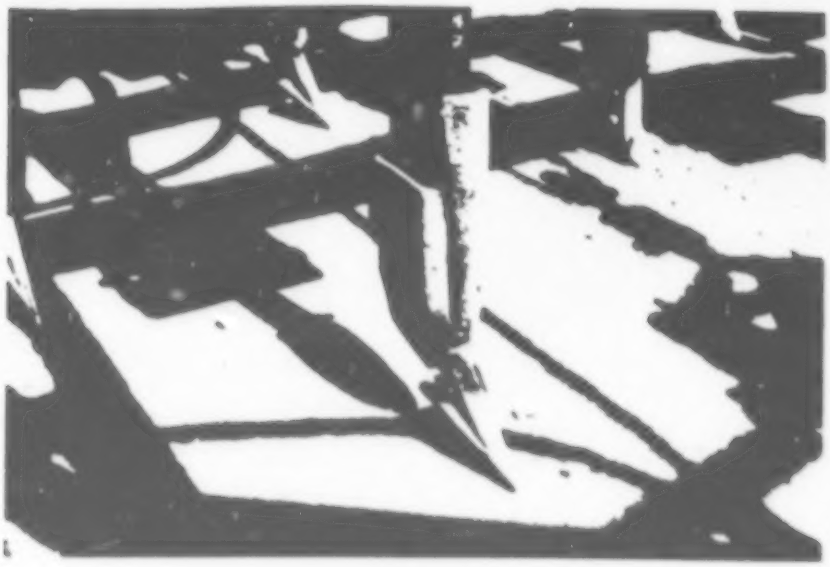

Fig. 3 ACRA-PLANT KNIFE OPENER

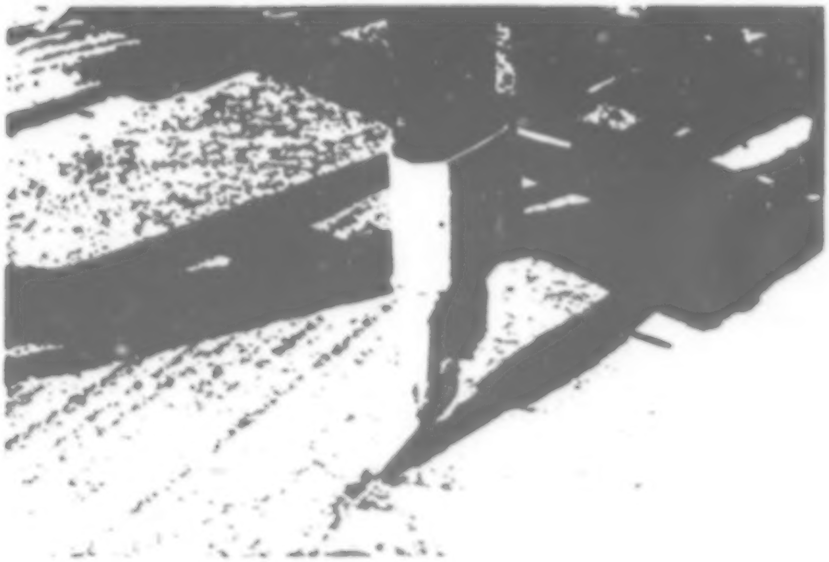

Fig. 4 VERSATILE KNIFE OPENER

Fig. 1 IHC HOE OPENER

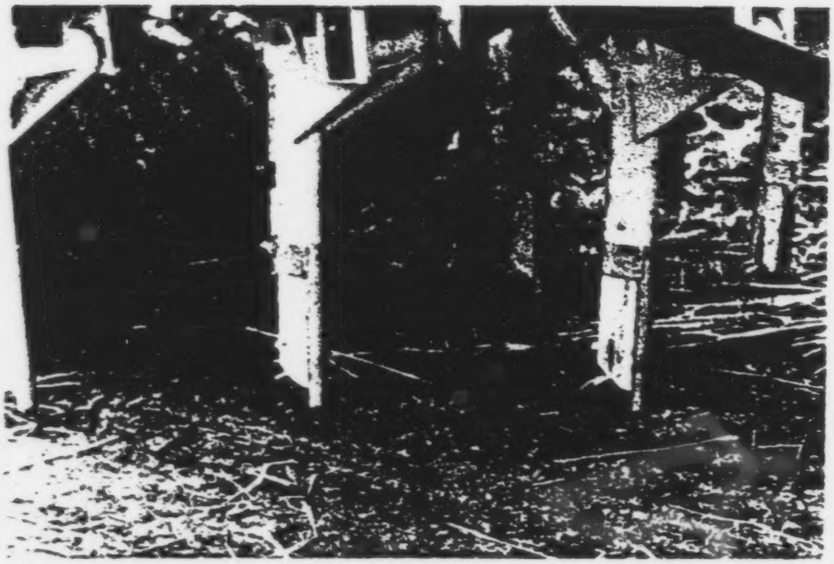

Fig. 2 EDWARDS HOE OPENER

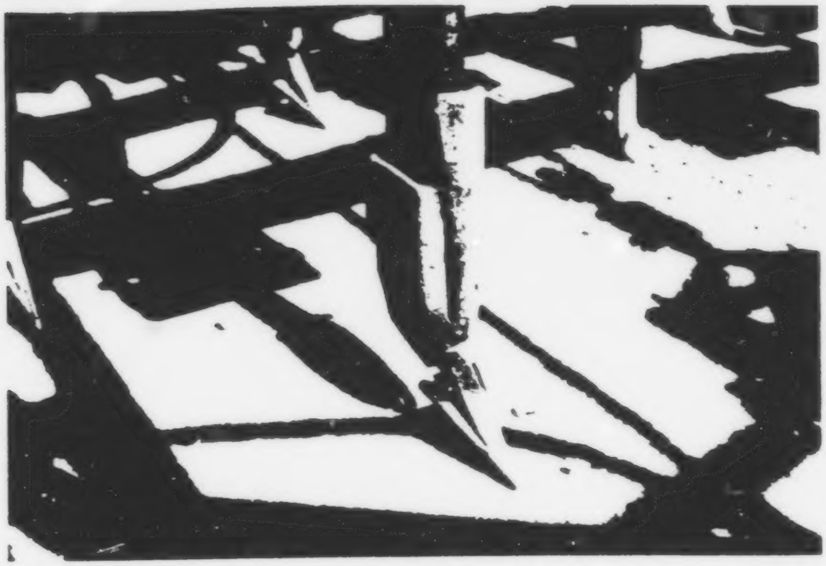

Fig. 3 ACRA-PLANT KNIFE OPENER

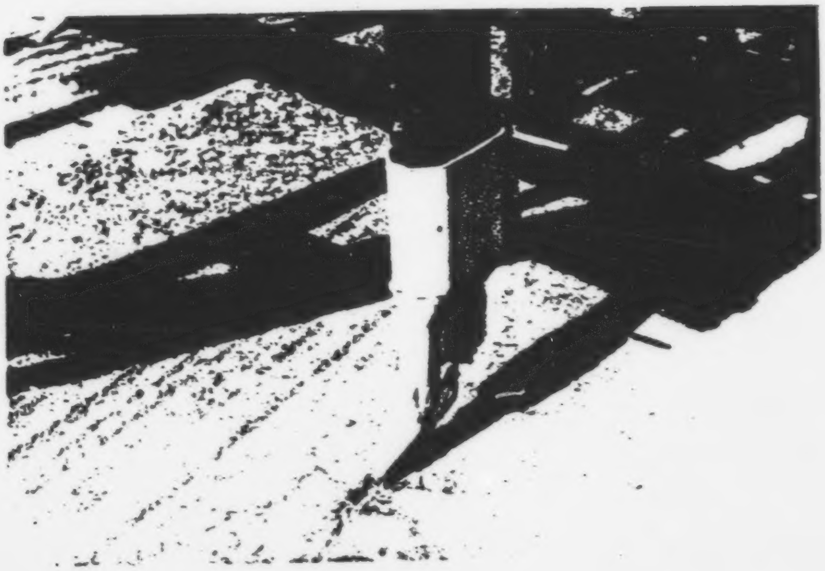

Fig. 4 VERSATILE KNIFE OPENER

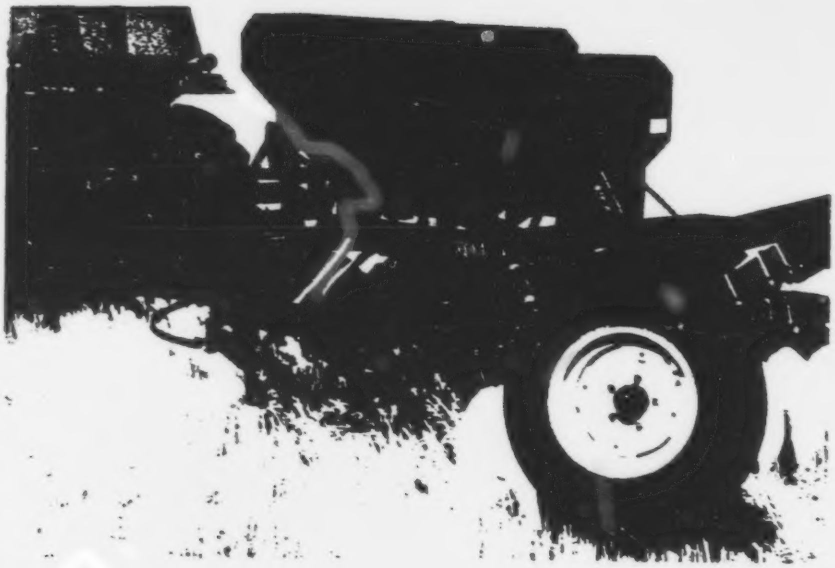

Fig. 5 EDWARDS HD812 HOE DRILL

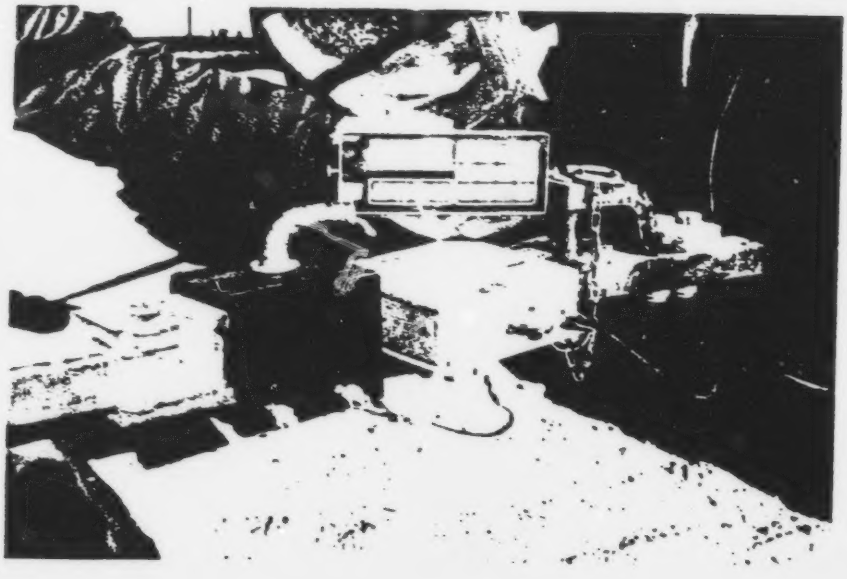

Fig. 6 FORCE TRANSDUCER AND DF2000
DIGITAL WEIGHT INDICATOR

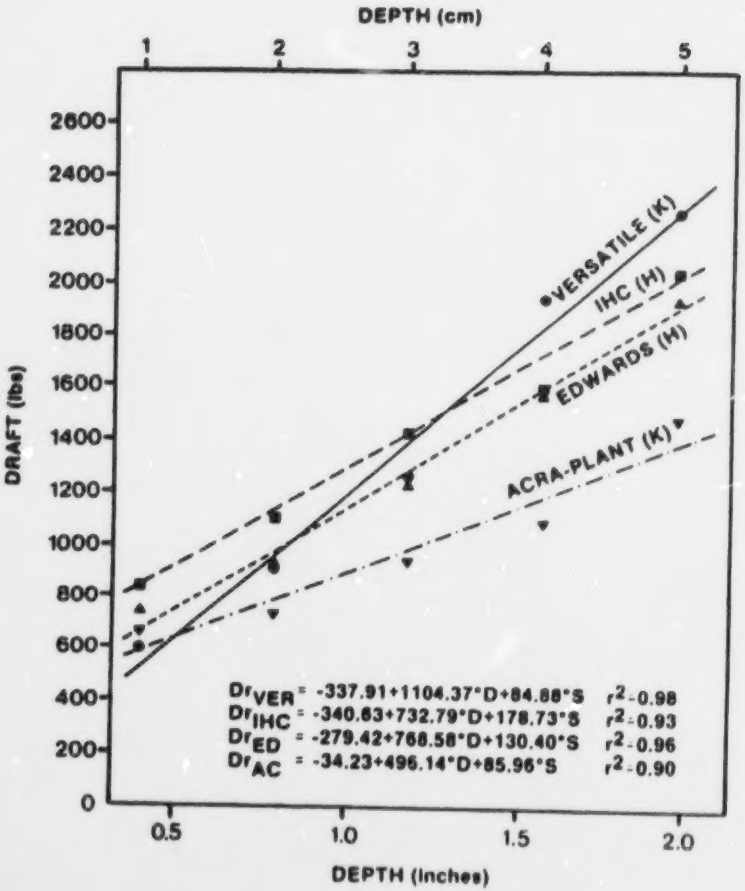

FIGURE 7. DRAFT VERSUS SEEDING DEPTH FOR FOUR TYPES OF OPENERS. AVERAGE SPEED WITH TEN OPENERS.

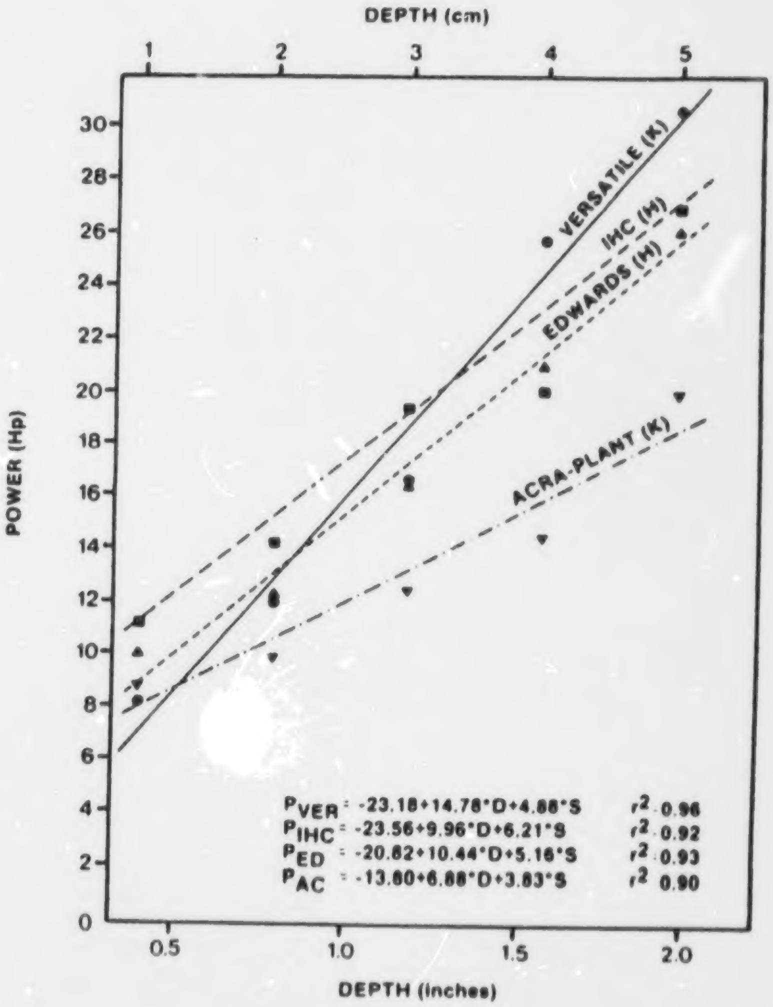

Figure 8. POWER REQUIREMENTS VERSUS SEEDING DEPTH FOR FOUR TYPES OF OPENERS. AVERAGE SPEED WITH TEN OPENERS.

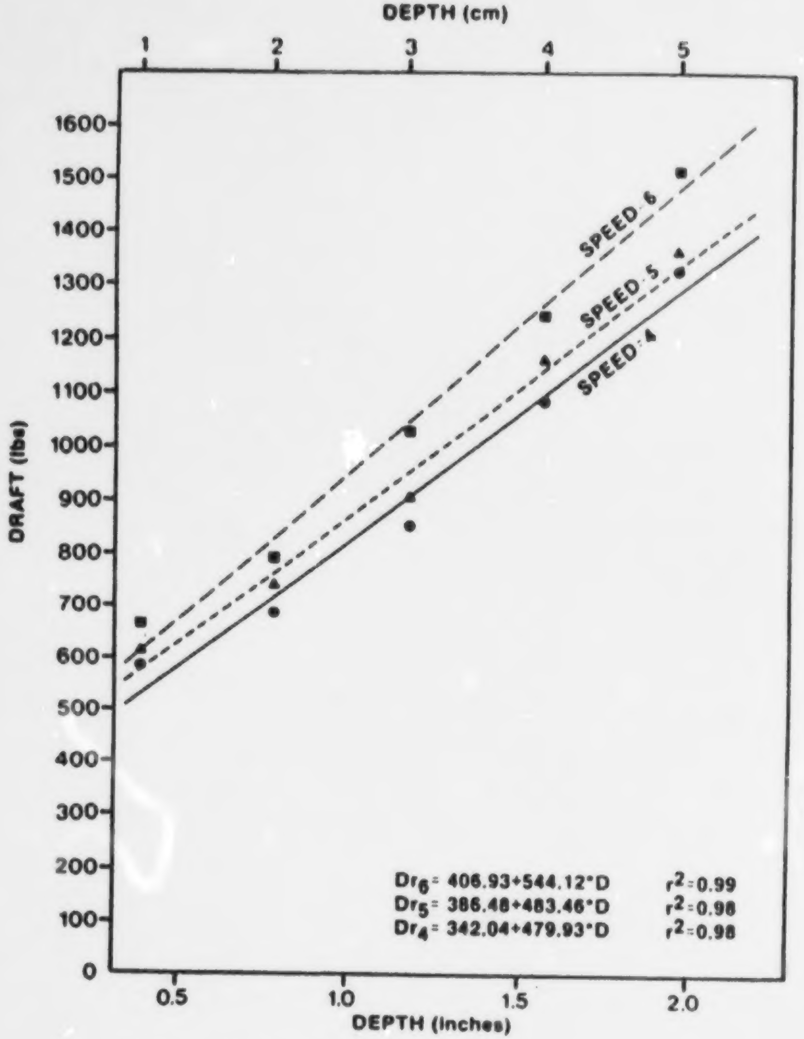

Figure 9. DRAFT VERSUS SEEDING DEPTH FOR THREE SPEEDS. AVERAGE DRAFT FOR ALL OPENER TYPES IN TRIALS WITH FOUR, SIX, EIGHT AND TEN OPENERS.

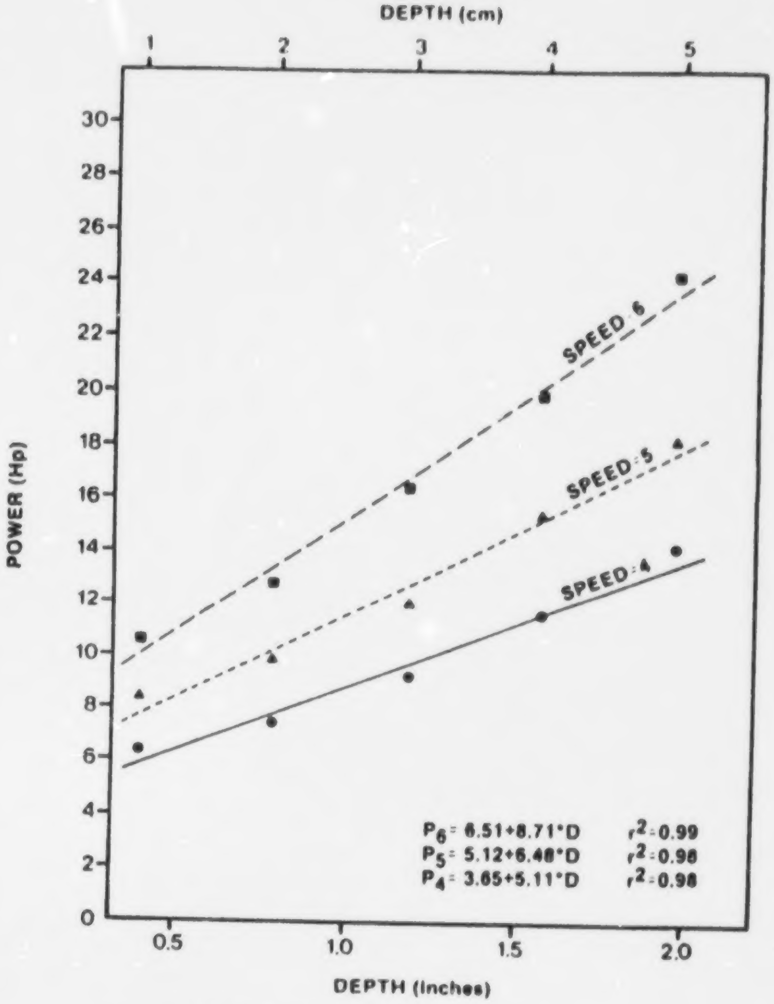

Figure 10. POWER VERSUS SEEDING DEPTH FOR THREE SPEEDS. AVERAGE POWER FOR ALL OPENER TYPES IN TRIALS WITH FOUR, SIX, EIGHT AND TEN OPENERS.

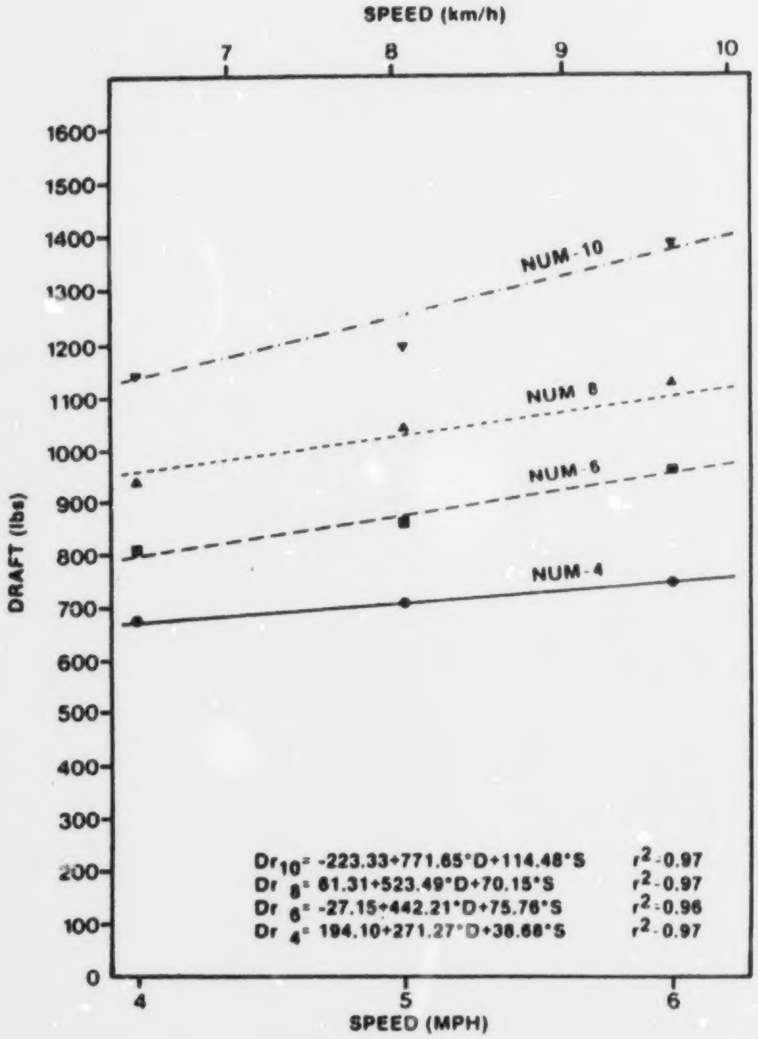

Figure 11. DRAFT VERSUS SPEED FOR FOUR, SIX, EIGHT AND TEN OPENERS, AVERAGE OF FOUR OPENER TYPES AND FIVE DEPTHS.

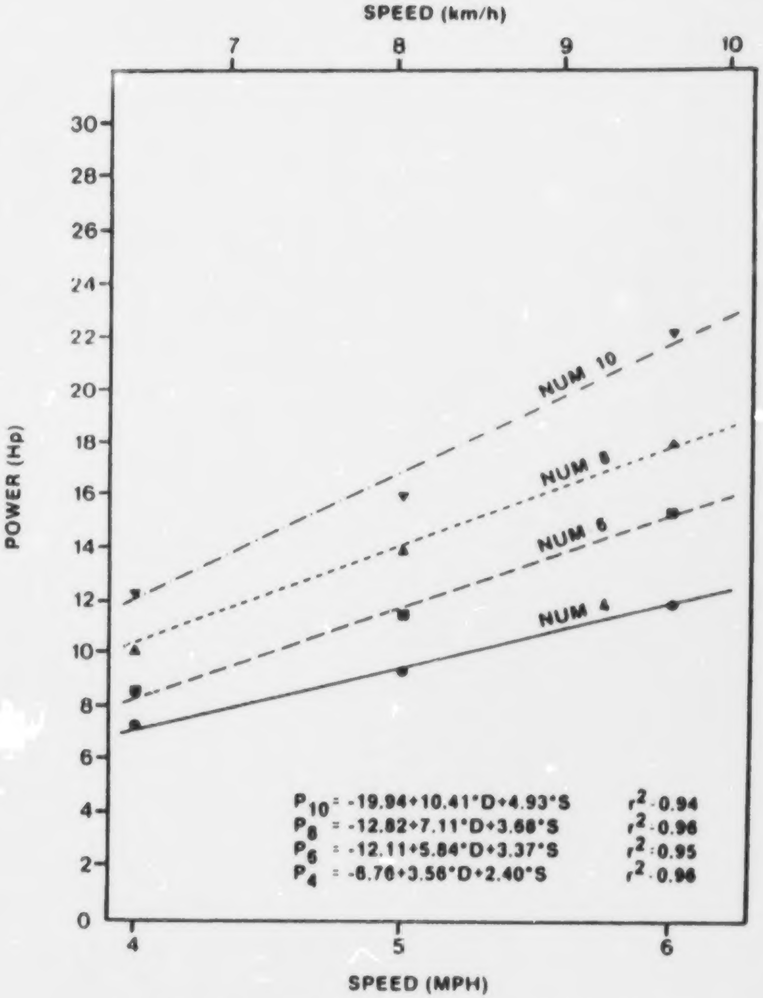

Figure 12. POWER VERSUS SPEED FOR FOUR, SIX, EIGHT AND TEN OPENERS, AVERAGE OF FOUR OPENER TYPES AND FIVE DEPTHS

The Effect of Stubble on Winter Survival of Winter Wheat

L.V. Gusta and H.M. Austenson

It has been observed that winter wheat sown into heavy wheat or barley stubble does not perform as well as when sown into canola or flax stubble. This study was initiated to determine the effect of stubble on overwintering and performance of winter wheat. Norstar winter wheat was sown into wheat and canola stubble plus into chemfallow and summerfallow. The cold hardiness of the crowns was monitored throughout the winter by controlled freeze tests.

Table 1: The Cold Hardineses Levels of Norstar Winter Wheat Crowns Sown Under Various Conditions, 1985.

	LT_{50}'s	
Fall Sown Stubble	December	February
Chemfallow	-20	-18
Rape	-22	-22
Summerfallow	-21	-16
Wheat	-19	-12
Spring Sown	-20	-22

Preliminary results rank the cold hardiness of winter wheat crowns in the following order: rape stubble, chemfallow, summerfallow and wheat stubble. These results suggest that wheat stubble affects the cold hardiness of winter wheat.

The cold hardiness of winter wheat sown in the spring was determined throughout the winter. To date the cold hardiness of spring sown winter wheat is equal or superior to the cold hardiness of winter wheat sown in the fall into rape stubble.

In the fall of 1986 Norstar winter wheat was sown into flax, lentils and barley stubble as well as those of 1985.

Stubble Study:

	LT_{50}'s				
	December '85	January '86	February	March	December
Summerfallow	**-20**	**-18**	**-14**	**- 9**	**-26**
Rape stubble	**-22**	**-18**	**-22**	**-19**	**-26**
Summerfallow	**-21**	**-14**	**-16**	**-19**	**-27**
Wheat stubble	**-19**	**-13**	**-12**	**-12**	**-26**
Spring seeded control	**-20**	**-19**	**-22**	**-20**	
Treated	**-22**	**-23**	**-22**	**-20**	
Barley					**-24**
Flax					**-26**
Lentils					**-25**

The Role of Growth Regulators on Overwintering of Winter Cereals

L.V. Gusta, B.J. O'Connor and M.J. Reaney

Giberellic acid (GA) has been demonstrated to decrease the cold hardiness of many plant species. Certain cultivars of winter wheat possess higher levels of GA than others. Generally, the more cold hardy cultivars contain low levels of GA during hardening. Plants sprayed with exogenous GA have reduced in freezing tolerance.

Plant growth regulations, Cycocel extra, Terpal C and Mefluidide were applied as a foliar spray on Norstar winter wheat plants at 3 concentrations. Plants were collected in the fall for controlled freeze tests to be conducted throughout the winter. Plants were again collected in the spring to test the plants' hardiness level. Non-sprayed plants tested for cold hardiness could tolerate -14°C at the beginning of March. Plants treated with growth regulators could tolerate -20°C.

Controlled freeze tests were conducted on eight cultivars of winter wheat sprayed with Terpal C at 3 concentrations. A differential response to spray concentration depending upon the cultivar was observed. Borden, Cimmaron and Monopol did not respond to Terpal C but Aggasiz, Norstar, Norwin and Redwin has a positive effect on cold hardiness in February.

Ten growth regulators were sprayed on Norstar winter wheat. Positive effects were seen with Bayleton, Culbac, Cycocel extra, Terpal, Terpal C and S3307 on the cold hardiness of Norstar crowns.

Survival of Norstar and Norwin winter wheat in the spring increased with seed treatments of two growth regulators from BASF (Gus, BASF 106).

Root regeneration is critical for plant establishment in the spring. The roots of winter cereals are killed at -6°C. Therefore, each winter the roots on winter wheat plants have to be reestablished. Thirty-two percent of the control plants did not produce roots in sand pots grown at 20°C for 10 days. Whereas, 40% produced one root, 16% produced two roots and 12% three roots. Plants treated with Cycocel extra did not produce more roots than the controls, however the roots produced were longer.

No significant effect on grain yield and final plant height was found with the fall application of growth regulators.

Growth regulators which arrest the loss of cold hardiness during the critical period of the end of January and beginning of February as well as enhance rooting in the spring would aid in stabilizing production of winter wheat in areas of limited snowfall.

Cold acclimation in winter cereals is induced by temperatures lower than 10°C. Energy for this process is supplied either from seed reserves or from photosynthesis. Maximum freezing resistance is obtained in early November, just after the soil freezes (Fig. 1). Thereafter the hardiness of the crowns remains constant until the end of December and then starts to decline. The loss in freezing tolerance during the winter months is dependent on weather, cultural practices and the cultivar sown.

Cultivars sown at the optimum date of seeding and grown under high light conditions cold harden to their full potential and maintain a high level of hardiness throughout the winter months. Plants during the hardening period if exposed to cloudy weather or to an early snowfall which stays, do not develop their full hardiness potential and do not maintain a high level of hardiness throughout the winter. High levels of nitrogen or phosphorous tend to result in a loss of cold hardiness in early January. Certain cultivars of winter wheat such as Gaines, Nugaines or Rideau are several degrees less freezing resistant than Norstar in early December. However, these cultivars rapidly lose their cold tolerance in January and February. The cultivars Norwin, Aggasiz, Winalta and Sundance in early December possess the same level of freezing tolerance as Norstar. From repeated field studies it has been established that Norstar has a higher field survival than these cultivars. Freeze tests demonstrate that Norstar maintains a higher level of cold hardiness throughout January to February than Norwin, Aggasiz, Winalta and Sundance.

Gibberellic acid (GA) has been demonstrated to decrease the cold hardiness of many plant species. Certain cultivars of winter wheat possess higher levels of GA than others. Generally the more cold hardy cultivars contain low levels of GA during hardening. Conditions of low light, high fertility favor the build up in GA. Plants sprayed with exogeneous GA are reduced in freezing tolerance.

The objectives of this study were three-fold. First, to determine the effect of anti GA compounds, applied in the fall, on the development and maintenance of cold hardiness in winter cereals. Second, to determine the effect of anti GA compounds on fall plant growth and development. Third, to determine the effect of anti GA compounds on final growth, maturity and yield.

MATERIALS AND METHODS: Plant growth regulators were applied on October 11, 1984 on Norstar winter wheat plants at the 3-leaf stage. The plants were sprayed with a hand-held boom sprayer (R&D Sprayers) with 10 gal/acre nozzles. The concentration of growth regulators were as follows: Cycocel extra 0.5, 1 and 2%; Terpal C .5, 1 and 1.5%; Mefluidide .075, .15 and .3%. Citowelt plus at a final concentration of 0.1% was added to all growth regulators to aid in uptake. Experimental design was a randomized complete block, replicated three times. Each plot consisted of 4 rows at one foot row spacing and 16 feet long.

Plant material was collected October 26, brought into the lab and analyzed for number of leaves, fresh weight and dry weight. Plants were also collected for controlled freeze tests run December 7, January 17, February 7, February 20, March 22, April 19 and May 9. Fall collected material was held in a controlled environment chamber with lights and a constant temperature of -4°C. Plants for the freeze test were trimmed 3 cm above and 1 cm below the crown. Plants were held at -3°C for 12 hours to initiate freezing and then cooled at 2°C/h. Plants were then removed from the freezer at 2°C intervals, thawed at 4°C and then transplanted to a soil, peat, vermiculite mixture (1:1:1, v/v/v). After 3 weeks at 22°C, the plants were then rated for survival, fresh weight, dry weight, and shoot length.

In the spring of 1985, plants were collected from the field April 23. Plant height, fresh weight, dry weight and root regeneration were determined on these plants. These plants were potted in sand in 4" pots, with one plant per pot and held at 20°C. After 10 days the plants were rated for shoot growth, fresh weight, dry weight, number of plants with roots, number of roots per plant and root length. In the study, 25 plants were used per treatment.

A controlled freeze test was also run on the spring collected plants. In the spring and summer of 1985, the plants in the plots were measured for plant height, tiller number, flag leaf area, distance from head to flag leaf, number of effective tillers, 1000 seed weight, yield and percent protein. These plots were harvested August 19.

On October 22, 1985 eight cultivars of winter wheat at the one- to two-leaf stage were sprayed with Terpal C at the same three concentrations used in 1984. Plants were collected from the field October 25 and stored at -4°C.

Five cultivars of winter barley, namely Dictoo, Dundy, Kearney, Marylin and a numbered cultivar were sprayed with Terpal C at a concentration of 2%. Plants were collected from the field October 25, 1985.

Ten growth regulators were sprayed on Norstar winter wheat on October 22, 1985. Three concentrations for each growth regulator was applied. Eight seed treatments were applied to Norstar and Norwin seeds prior to planting. Plants were collected from the field October 26, 1985.

RESULTS AND DISCUSSION: Cycocel extra, Terpal C and mefluidide had no effect on fresh weight, dry weight, leaf number and leaf length or plants collected October 26, 1985, as compared to the controls.

Plants from all treatments tested on December 7 could tolerate -25°C (Table I). On January 16, control plants, maintained in storage at -4°C, had an LT_{50} of -19°C. Plants treated with Cycocel extra, Terpal C, and mefluidide, at all concentrations, had an LT_{50} on average of -22°C. With storage time, there was a rapid loss in cold tolerance of the control plants by February (LT_{50} - 15°C). The crowns of plants treated with Cycocel and Terpal C could tolerate -22°C. Soil temperatures traditionally are the coldest at the end of January and the beginning of February. The crowns of plants treated with mefluidide at the higher concentrations were less hardy than the plants treated with Cycocel and Terpal. Control plants tested for cold tolerance on March 21 had a LT_{50} of -11°C. At this date there was little change in the cold tolerance of the plants treated with Cycocel and Terpal C. However, there was a loss of 5 to 6°C in freezing tolerance in the crowns of plants tested for freezing tolerance on April 18, 1985.

Plants were collected from the field on April 23, 1985, stored at -3°C and tested for cold tolerance on April 30. At this time there was little or no difference between treatments for freezing tolerance.

Plants collected from the field April 23, 1985 and potted in sand for 10 days at 20°C were analyzed for root number and length (Table II). Eight out of twenty-five plants in the control did not produce roots in the 10 day period. Whereas 10 plants produced one root, 4 plants produced two roots and 3 plants produced three roots. Plants treated with Terpal C produced more and longer roots than the control plants. Plants treated with Cycocel did not produce more roots than the control, however the roots produced were longer than the control.

Root regeneration is critical for plant establishment in the spring. Our research has demonstrated that the roots of winter cereals are killed at -6°C. Therefore, each winter the roots on winter wheat plants have to be reestablished. For areas of low rainfall, new strong, healthy roots must be produced quickly before the soil surface dries out. Roots produced in a dry soil will either not grow or die due to desiccation.

Terpal C, Cycocel and Mefluidide applied in the fall had no significant effect on grain yield and final plant height. Therefore, the anti GA effects of these growth regulators are overcome by spring and summer growth.

A similar response to growth regulators was observed in the fall of 1985 and winter of 1986, as was observed in 1984/1985. Growth regulators had no effect on the cold hardiness of the crowns frozen in December. Plants sprayed with Terpal C, Cycocel, Bayleton, Mefluidide and S-3307 were more freezing tolerant than the controls in February (Table III). Terpal C had a positive effect on the cold hardiness of Aggasiz, Norstar, Norwin and Redwin tested in February. There was a differential response to concentration depending upon the cultivar. The cultivars Borden, Cimmaron and Monopol did not respond to the Terpal C treatment.

Terpal C had a positive effect on the cold tolerance of Aggasiz, Norwin, Norstar and Redwin in late December. This freeze test differed from the above in that the plants were held at -18°C for up to seven days. Each day plants were removed from the freezer and replanted in a recovery room. This test was to simulate a period of prolonged cold as was observed in November of 1985.

A summary of the effects of growth regulators on the cold tolerance of Norstar winter wheat tested February 11 is presented in Table IV. Bayleton, Culbac, Cycocel plus, Terpal, Terpal C and S-3307 had a positive effect on the cold hardiness of crowns at this date.

Although these results appear promising much more research has to be conducted to verify the positive effects of growth regulators. The ability to increase the cold tolerance and enhance rooting is of particular importance to winter wheat production in western Canada.

Fig. I. Graphical representation of the freezing tolerance for winter wheats. Line 1 represents the freezing tolerance of less hardy winter cultivars such as Gaines, Nugaines and Rideau. Line 2 represents the freezing tolerance of Aggasiz, Norwin, Winalta and Sundance. Line 3 represents the freezing tolerance of the most hardy winter wheats such as Norstar and Kharkow. Line 4 represents the ideal winter hardiness for a winter wheat cultivar.

Table I. Freezing Tolerance of Norstar Crowns

Treatment Conc. (%)	LT$_{50}$ (°C)					
	Dec. 7	Jan. 16	Feb. 20	Mar. 21	Apr. 18*	Apr. 30
Control	-26	-19	-15	-11	-11	-14
Cycocel 0.5	-26	-23	-23	-20	-14	-13
1.0	-26	-21	-21	-20	-15	-12
2.0	-26	-23	-25	-20	-14	-11
Terpal C 0.5	-26	-22	-22	-21	-17	-12
1.0	-26	-21	-22	-22	-15	-13
1.5	-26	-22	-22	-22	-15	-15
Mefluidide 0.075	-26	-23	-23	-19	-16	-12
0.15	-26	-23	-18	-22	-12	-12
0.3	-26	-22	-18	-14	-17	-12

* - Plants collected from the field in the spring on April 29 and frozen on April 30.

Table II. The Effect of Fall Applied Growth Regulators on the Spring Regeneration of Roots

Treatment Conc. (%)	Number of Plants With Roots			
	Root Number			
	0	1	2	3
Control	8	10 (15.1)	4 (8.75)	3 (11.8)
Cycocel 0.5	12	9 (15.1)	4 (26.6)	0
1.0	12	8 (30.4)	5 (19.2)	0
2.0	10	6 (23.5)	6 (16.25)	3 (14.0)
Terpal C 0.5	2	7 (22.3)	13 (18.8)	2 (23.4)
1.0	5	12 (25.4)	6 (28.3)	2 (16.2)
1.5	5	12 (21.8)	8 (17.9)	0
Mefluidide 0.075	16	7 (13.1)	2 (10.3)	0
0.15	2	15 (21.6)	6 (21.3)	2 (27.0)
0.3	8	9 (33.3)	6 (29.7)	2 (23.8)

Value in parenthesis indicate average root length.

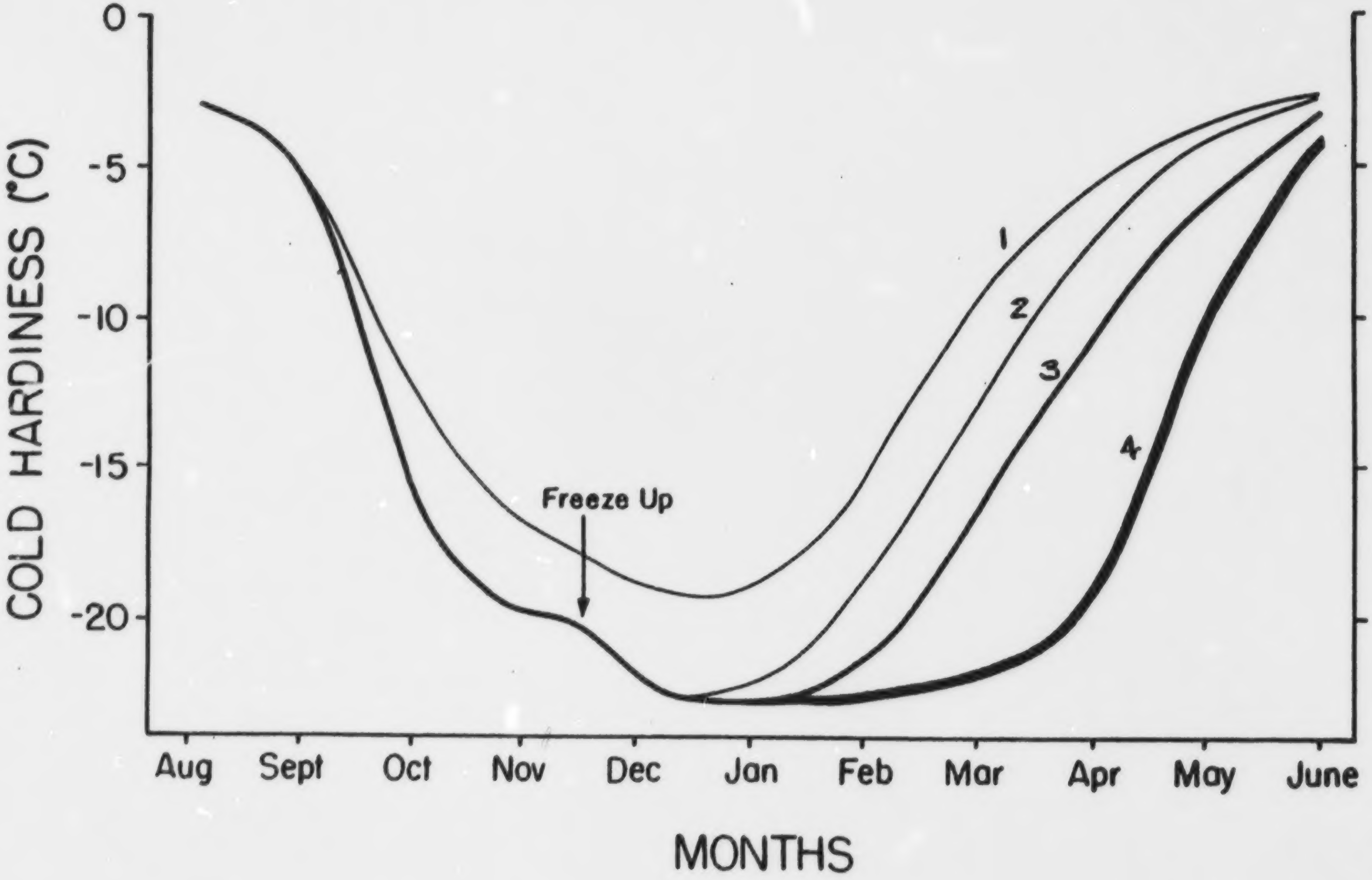
9
COLD HARDINESS (°C)
0
-5
-10
-15
-20
Freeze Up
1
2
3
4
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
June
MONTHS

Table III. The Effect of Terpal C on the Cold Hardiness of Winter Wheats Tested February 12, 1986

Cultivar	Terpal C (%)	LT_{50} (°C)
Aggasiz	Control	-14
	0.5	-16
	1.0	-15
	2.0	-22
Borden	Control	-13
	0.5	-10
	1.0	-13
	2.0	-11
Cinmaron	Control	-15
	0.5	-15
	1.0	-13
	2.0	-10
Houser	Control	-10
	0.5	-17
	1.0	-13
	2.0	-10
Monopol	Control	-12
	0.5	-10
	1.0	-10
	2.0	-13
Norwin	Control	-12
	0.5	-16
	1.0	-16
	2.0	-21
Redwin	Control	-17
	0.5	-20
	1.0	-16
	2.0	-21

Table IV. The Effect of Growth Regulators on the Freezing Tolerance of Norstar Winter Wheat Tested February 11, 1986

Growth Regulator	LT_{50} (°C)
Control	-17
Bayleton	-19
Cycocel^{+}	-20
Cerone	-18
Culbac	-20
Mefluidide	-19
Terpal	-20
Terpal C	-20
S-3307	-20
S-3308	-18

The Effect of Nitrogen and Phosphorus on the Cold Hardiness of Winter Wheat in the Field

L.V. Gusta, G. LaFond and H.M. Austenson

Previous research has established that phosphorus enhances the overwintering ability of plants, while high levels of nitrogen decreases the cold hardiness of plants. High levels of nitrogen are required to optimize the yield potential of winter wheat. Studies were initiated to determine the effect of nitrogen and phosphorus on the cold hardiness and winter survival of Norstar winter wheat.

Nitrogen and phosphorus was applied at 3 rates, either alone or in combination with each other in the fall. These fertilizers were either applied with the seed or broadcast.

Table 1: Fertilizer rates.

Seed placement:		
P_1 16.9	P_2 33.9	P_3 50.9 (lbs/acre)
N_1 38.7	N_2 78.7	N_3 118.7
Broadcast:		
P_1 16.9	P_2 33.9	P_3 50.9 (lbs/acre)
N_1 26.1	N_2 65.8	N_3 106.0

High levels of nitrogen does not affect the level of cold hardiness in early December. However, plants treated with high rates of nitrogen lose hardiness at a faster rate than plants fertilized with low rates of nitrogen (Table 2).

Nitrogen levels in the crown tissue were determined (Table 3). As the nitrogen levels were increased in the soil, nitrogen levels increase in the crown. Seed placement of fertilizer winter wheat crowns tended to have higher nitrogen levels. Initial nitrogen levels for the seed placement treatments had higher nitrogen levels.

Phosphorus tends to arrest the loss of cold hardiness in crowns.

Winter wheat crowns where the fertilizer was broadcast had cold hardiness levels 10% lower than the seed placement treatments. These crowns tended to lose the cold hardiness faster.

Phosphorus also stimulates root regrowth in the spring (Table 4). New roots are produced in the spring from the base of the crown. The roots produced the previous fall are winterkilled. Early root regeneration in the spring is required for plant establishment and avoidance of drought.

Table 2: The Effect of Various Levels of Phosphorus and Nitrogen on the Cold Hardiness of Winter Wheat Crowns, 1985-86.

Fertilizer levels		Seed Placement			Broadcast		
		December	January	February	December	January	February
		LT_{50} (°C)			LT_{50} (°C)		
P_0	N_0	-25	-23	-18	-23	-21	-18
	N_1	-22	-22	-16	-25	-21	-16
	N_2	-23	-19	-16	-24	-20	-16
	N_3	-22	-20	-16	-23	-21	-18
P_1	N_0	-26	-23	-17	-23	-22	-17
	N_1	-25	-23	-19	-23	-17	-16
	N_2	-25	-23	-15	-25	-15	-16
	N_3	-22	-20	-11	-19	-17	-16
P_2	N_0	-25	-22	-17	-25	-17	-18
	N_1	-25	-21	-16	-21	-22	-14
	N_2	-25	-19	-13	-25	-16	-13
	N_3	-23	-18	-14	-23	-19	-16
P_3	N_0	-25	-23	-18	-22	-21	-13
	N_1	-24	-19	-16	-25	-21	-14
	N_2	-25	-23	-13	-25	-16	-14
	N_3	-18	-15	- 9	-25	-16	-13

Table 3. Nitrogen Levels (% Nitrogen Microkelgon) Present in the Crowns when Collected in November, 1985.

		Nitrogen content (% nitrogen microkelgon)	
		Seed Placement	Broadcast
P_0	N_0	19.5	17.9
	N_1	23.1	21.8
	N_2	23.2	23.2
	N_3	25.8	22.1
P_3	N_0	19.8	29.0
	N_1	29.4	39.0
	N_2	30.6	30.6
	N_3	29.4	28.5

Table 4. Total and Root Biomass (g) of New Growth from Winter Wheat Crowns Collected in the Spring of 1986.

Fertility Level		Root Biomass	Total Biomass
P_0	N_0	.23	.57
	N_1	.25	.60
	N_2	.37	.63
	N_3	.26	.60
P_1	N_0	.29	.65
	N_1	.44	1.04
	N_2	.41	.97
	N_3	.51	1.13
P_2	N_0	.29	.66
	N_1	.32	.72
	N_2	.37	.83
	N_3	.41	.95

CONCLUSIONS AND IMPACT

1. The observation the ABA can increase the cold tolerance of winter wheat at non-hardening temperatures under sterile conditions. This makes it theoretically possible to harden plants to unseasonal frosts.

2. The identification of proteins involved in the expression of freezing tolerance is of fundamental importance.

3. The observation that ABA increases resistance to salt osmotic and heat stresses in model systems greatly multiplies the potential economic importance of studying the mechanism by which ABA increases resistance to plant stresses.

4. The triticale line 81DE01015 exhibits both good hardiness and hardiness for an extended period through the winter, depending upon seeding date.

5. Ice nucleating bacteria found to be present on cereal and oil seed crops in Saskatchewan are: **Pseudomonas syringae** which caused freezing at -2 to -3°C and **Erwinia herbicola**.

6. Plant growth regulators have been found to have a positive effect on the cold hardiness levels of winter wheat as well as enhance rooting.

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C2 CROP DEVELOPMENT CENTRE PHYSIOLOGY PROGRAM 1986-87

INDUCTION BY ABA AND AGING OF CULTURE OF FREEZING, HEAT, SALT AND OSMOTIC TOLERANCE IN BROMEGRASS, CULTURED CELLS AND ITS RELATION TO OSMOLARITY AND WATER CONTENT

M. ISHIKAWA, A.J. ROBERTSON, L.V. GUSTA

ABSTRACT: Bromegrass cells (Cell line V-2 1 g inoculum) was incubated in half strength Erikson's media in the presence or absence of 7.5×10^{-5}M abscisic acid (ABA) in the dark at 25°C for 0 to 14 days. Freezing, heat, salt and osmotic stress tolerance of these cells were followed as well as the fresh weight increase, water content and cell osmolarity. The cells grown with ABA showed greater resistance to freezing, heat, salt or osmotic stress at all the periods of incubation than cells in the control culture. The extent of resistance of ABA treated cells to these stresses increased with longer period of incubation. This stress tolerance increase was accompanied by the concomitant water content decrease, which may be due to augmentation of cells.

In control culture, meanwhile, the tolerance for these stresses once decreased from lag phase (3.5 d) to log phase (6.5 d) of growth, then increased as the culture went into the early stationary stage (10.5 d). Meantime, the water content of control cells once decreased at early stage of growth, then gradually increased and there was not a good correlation with the stress tolerance. The culture period dependent fluctuations in stress tolerance or the aging induced stress tolerance increase in control cells may be attributed to the concurrent ups and downs in the cell osmolarity. ABA treated cells should similar fluctuations in osmolarity as the control, after 14 days of culture. There seemed to be no apparent correlation between stress tolerance and osmolarity level in the ABA treated cells, especially at the early stages of growth (3.5 and 6.5 d).

Selection of Frost Resistant Spring Plants

L.V. Gusta, B.J. O'Connor and R.J. Woloschuk

The frost hardiness of the currently grown cultivars of wheat, barley, oats, rape and mustards was determined. Wheat is the most frost tolerant spring crop followed closely by barley, oats, flax, mustard and canola.

Canola plants in the cotyledon stage are very frost sensitive (-2 to -3°C). At the 4 to 6 leaf stage they are able to tolerate a frost of -4°C. The flowers and pods of canola are more sensitive to freezing than the leaves.

Freezing of cereals at the early dough stage had a significant affect on yield and seed germination, whereas at the late dough stage there was only a slight effect.

Ice nucleating active bacteria, **Pseudomonas syringae** and **Erwinia herbicola** were found to play a role in causing plants to freeze in Western Canada. Bacterial populations with ice nucleating ability increase from spring to fall and as plants approached maturity, their leaves froze at progressively warmer temperatures. Plants in 1985 and 1986 (cool and moist season) tended to freeze at warmer temperatures in the summer and fall than plants in 1984 (hot and dry season).

Oats, on average, had the highest population of ice nucleating bacteria.

P. syringae tended to cause plants to freeze at -2 to -3°C whereas **E. herbicola** found in lesser quantities was also less effective at initiating freezing.

A. Introduction

In the last eight years, Western Canada has had widespread killing frosts on August 13, 1979, August 23, 1982, August 30, 1985 and August 25, 1986. From weather reports, localized frosts has occurred in many northern areas of Western Canada.

Unseasonal frosts result in complete crop loss, yield reduction and reduced quality. Spring frosts, e.g. June 4, 1985, result in delayed maturity or in reseeding of the crop which is then prone to fall frosts. In 1985, over 50% of the canola crop in Saskatchewan graded sample. This year, due to the late wet fall combined with frost, it is expected that more than 50% of the canola crop will not grade number one. Green seeds produced as a result of the frost have to be bleached by the crusher before it is acceptable for export to Japan. This costs the crusher an additional $25 to $30 per metric ton. The oil produced from frosted seeds is much darker and is not as high a quality as is expected for export. Fall frost, therefore, limits a potential market requiring high quality seed for flour and oil markets.

In the last three years, we have done a comprehensive study on the frost resistance of our current cultivars of wheat, barley, oats, flax, canola and mustards.

The objectives of this study are: first, to determine the frost hardiness of the currently grown cultivars of wheat, barley, oats, rape and mustards;

second, to determine what nucleators are present in plants that cause them to freeze and how they can be inhibited.

B. Frost Tolerance of Spring Crops

Seven varieties of wheat and oats, and eight varieties of barley were sown in the field. Six varieties of rape and four of mustard were also sown at the research plots at the University of Saskatchewan, at Saskatoon. Starting from time of emergence to final maturity, plants were collected from the field, brought to the laboratory and tested for frost tolerance. One-half of the plants were nucleated with ice at -3°C to insure that the plants froze. The other half of the plants were allowed to freeze depending on the nucleators present in their leaves. The results of this study are summarized in Table 1.

Wheat leaves which were not nucleated with ice at -3°C could withstand a colder frost than leaves nucleated with ice. The difference was consistently 2°C throughout the growing season. Plants from June to July could tolerate from -5.5° to -7.5°C of frost. In the middle of June, plants could only tolerate -3° to -5°C of frost. By the middle of August, wheat leaves regained their original spring frost tolerance (-5.5° to -7.5°C of frost).

The frost tolerance of barley was very similar to that of wheat. Again, if the plants were not nucleated with ice at -3°C, they could withstand more frost than those plants nucleated with ice. The frost tolerance of oats was considerably less than that of either wheat or barley. This is in agreement with last year's results. Oats at the middle of June could tolerate -6°C of frost, but in the middle of July, could only tolerate -2.5°C of frost.

Canola leaves were very frost sensitive in early spring at the cotyledon stage. Many cultivars were killed from -2.5° to -4.5°C, depending if they were nucleated at -2°C with ice. With plant development, the plants could tolerate more frost. At the beginning of July, plants could tolerate from -4° to -6.5°C of frost. However, by the beginning of August, they could only tolerate -3.5° to -4.5°C of frost. The mustards had a similar level of frost tolerance as the rape varieties.

Table 1. Frost Tolerance of Cereal Grains, Rape and Mustards

	Frost Tolerance (LT_{50} °C)											
	June 10		June 24		July 8		July 22		Aug. 9		Aug. 19	
Species	+	-	+	-	+	-	+	-	+	-	+	-
Wheat	-5.7	-7.5	-5.7	-7.5	-6.35	-8.5	-3	-5	-6	-7	-6	-8.5
Barley	-6.3	-7	-6	-8	-5	-8	-4.5	-6.5	-6	-7	-7	-10
Oatss	-6	-6.5	-4	-6	-2.5	-3.5	-2.5	-2.7	-3.5	-4.5	-7	-8.5
Canola	-2.5	-4.5	-4	-5	-4	-6.5	-3	-4.3	-3.5	-4.5	-4.5	-5.3
Mustard	-3	-5	-4.2	-5	-4.2	-6.7	-3.3	-3.6	-4	-5	-4.2	-5.0

+ nucleated with ice at -2.0° to cause plants to freeze.

- not nucleated with ice.

LT_{50} - temperature at which 50% of the leaves were killed. Plants cooled at 2°C/hour.

Wheat varieties - Benito, Columbus, Glenlea, HY320, Katepwa, Neepawa, Sinton.
Barley varieties - Argyle, Bonanza, Fairfield, Harrington, Klages, Klondike, Melvin, Summit.
Oat varieties - Calibre, Cascade, Dumont, Fidler, Harmon, Kelsey, Random.
Rape varieties - Altex, Westar, Candle, R-500, Tobin, Torch.
Mustard varieties - Domo, Leth 22A, Gisilba, Ekla.

C. The Effect of a Frost on Maturity and Yield of Cereals

Plants of wheat, barley and oats at the two-leaf stage were subjected to a frost ranging from -4° to -10°C. Following the frost, plants were transplanted in a greenhouse and then rated for survival, date of maturity, number of heads and yield. On an average, a frost of -4° to -6°C tended to increase the number of heads per plant particularly in Benito, Katepwa, Neepawa and Columbus. This phenomena was not observed in the barley and oat varieties tested. This effect should be studied more in detail. A frost of -4° to -10°C tended to delay maturity anywhere from 1 to 10 days, particularly in all varieties of wheat. This effect was less pronounced in oats and certain cultivars of barley. Melvin, Summit, Argyle and Fairfield required fewer days to mature following a frost.

The yield of spring wheat following a frost was often higher as compared to the non-frozen plants. Frosts in general tended to reduce the yield of all oat and barley varieties.

D. The Effect of a Fall Frost at the Early and Late Dough Stage of Cereals

Benito, Columbus, Glenlea and Neepawa wheats were grown outside in pots. At the early and late dough stage, one half the population was sprayed with ice nucleating bacteria (INA) and the other half with distilled water. The plants were then cooled to -4, -6 and -8°C. Following the frost, plants were grown to maturity, and the seed was harvested. The seed taken from these plants was also tested for germination. Results from this study are summarized in Table 2.

A frost of -4°C did not affect the yield and kernels per head of wheat frozen in the early dough stage. Plants frozen to -6°C or colder were reduced in kernel yield and kernels per head. Germination of the seed was reduced from 99% for the control to 65% for plants frozen to -8°C.

Wheat plants frozen in late dough (32% moisture content) sustained less injury than the plants frozen in the early dough stage. Yield, kernels per head and seed germination were not markedly reduced even by a frost of -8°C.

The yield and kernels per head of barley plants in the early dough stage (54% moisture content) frozen to -8°C was not markedly reduced as compared to the non-frozen. However, the germination of seeds from plants frozen to -8°C was reduced to 35% as compared to 75% for the non-frozen control. Of the barleys tested, Harrington had the highest germination rate (93%) and Melvin had the lowest germination rate (43%). The barley seeds were germinated in petri dishes with an excess amount of water available for germination. It is not known if Harrington is more resistant to these conditions than Melvin. Work is underway to test if Harrington can tolerate wet conditions better than Melvin. Barley plants frozen in late dough (17% moisture content) were not affected by a frost of -8°C as determined by the yield, seeds per head and germination.

Oat plants in the early dough stage (52% moisture) were reduced in yield by a frost of -6°C. Plants sprayed with INA bacteria sustained more injury than plants sprayed with distilled water. The reduction in yield was due in part to a reduction in the number of kernels per head. The germination of seeds from plants sprayed with INA bacteria and frozen to temperatures of -6°C and lower, was drastically reduced. There was essentially no germination of seeds taken from plants frozen to -8°C.

Oat plants, frozen in the late dough stage (21% moisture content) were not dramatically affected by a frost as low as -8°C. Seed germination was reduced to 20% as compared to the non frozen control.

Table 2. The Effect of a Frost on Wheat, Barley and Oats at the Early and Late Dough Stage

Species	Yield (g)	Kernels/ head	% Germ.	Yield (g)	Kernels/ head	% Germ.
Wheat KMC	60%			32.4%		
Control	5.50	16.7	99	5.50	16.7	99
-4	5.37	16.9	98	4.09	15.1	99
-4 (INA Bact.)	5.12	15.3	95	4.33	15.0	98
-6	2.80	14.3	89	5.48	15.7	94
-6 (INA Bact.)	2.40	12.6	84	5.10	15.5	95
-8	3.08	14.3	66	4.85	14.1	95
-8 (INA Bact.)	2.99	15.0	67	4.35	13.9	97
Barley KMC	53.6%			17.3%		
Control	5.46	14.8	72	5.46	14.8	72
-4	5.79	12.5	81	4.61	11.8	74
-4 (INA Bact.)	6.00	14.2	73	6.30	17.1	73
-6	4.60	12.8	62	5.10	13.4	77
-6 (INA Bact.)	5.08	14.3	69	4.40	11.6	74
-8	4.30	17.6	40	4.36	12.5	74
-8 (INA Bact.)	4.48	15.3	35	5.71	13.3	69
Oats KMC	51.7%			21%		
Control	7.11	27.9	89	7.11	27.9	89
-4	7.13	26.9	90	6.62	28.2	86
-4 (INA Bact.)	6.61	23.7	80	5.76	23.5	81
-6	5.38	26.5	70	6.31	27.7	73
-6 (INA Bact.)	3.59	19.9	23	6.21	23.0	74
-8	4.22	19.5	4	8.63	27.8	67
-8 (INA Bact.)	4.80	25.0	7	6.39	23.0	67

+KMC - kernel moisture content at the time of freeze.
INA - ice nucleating active bacteria.

E. The Effect of a Spring Frost on the Number of Days to Bolting and Flowering in Rape

Five cultivars of rape, namely, Altex, Westar, Tobin, Torch and Midas were frozen to -4, -5, and -6 at the 1 to 3 and 4 to 6 leaf stage of growth (Table 3). One half of the population was sprayed with ice nucleating bacteria and the other half sprayed with distilled water. The results of the 5 cultivars were combined. A frost of -4°C at the 1 to 3 leaf stage had a significant effect on the number of days to bolting and flowering. Plants sprayed with INA bacteria and frozen to -5°C took 9 more days to flower than plants frozen to -5°C.

Plants frozen at the 4 to 6 leaf stage were more frost tolerant than plants frozen at the 1 to 3 leaf stage. A frost of -5 and -6°C had a significant effect on the number of days to bolt and flower.

Table 3. The Effect of a Frost on the Number of Days to Bolting and Flowering of Rape

	Leaf growth stage at time of frost			
	1 to 3		4 to 6	
	Bolting	Flowering	Bolting	Flowering
Not frozen	54	59	44	51
-4	60	68	44	51
-4 (Bact.)	65	74	45	51
-5	65	68	51	59
-5 (Bact.)	65	77	50	59
-6	60	68	50	57
-6 (Bact.)	66	74	53	61

The average of 5 cultivars: Altex, Westar, Tobin, Midas and Torch.
Bact. refers to plants sprayed with ice nucleating bacteria.

F. The Effect of a -4°C Frost at Flowering on the Yield of Rape and Mustard

A frost of -4°C at the time of flowering did not affect the yield of rape and mustard plants if they were not sprayed with INA bacteria (Table 4). These plants escaped the frost by supercooling. Plants sprayed with INA bacteria and frozen to -4° had a significant yield reduction as compared to the non-frozen control. The yield of Altex, Midas and Westar was not reduced to the same degree as Tobin and Torch. The early flowering habit of these two cultivars may have been the reason for the large loss in yield.

The mustard, Domo, when frozen to -4°C, suffered a significant reduction in yield as compared to the more frozen control. The yield of Gisilba was reduced if sprayed with INA bacteria and then frozen to -4°C.

The flowers of rape and mustard are the first part of the plant to freeze if not sprayed with INA bacteria. The leaves tend to freeze a degree or so colder. Therefore, a fall frost may not injure the leaves but would have a significant effect on the yield and quality of oils.

Table 4. The Effect of a -4^{o} Frost at Flowering on the Yield of Rape and Mustard.

Cultivar	Yield (gms)
Rape	
Altex NF	3.45 a
Altex	3.04 a
Altex + INA	1.45 b
Midas NF	3.41 a
Midas	3.11 a
Midas + INA	2.17 b
Tobin WF	1.38 a
Tobin	1.35 a
Tobin + INA	0.06 b
Torch NF	1.14 a
Torch	2.00 a
Torch + INA	0.03 b
Westar NF	3.44 a
Westar	3.72 a
Westar + INA	2.01 b
Mustard	
Domo NF	2.34 a
Domo	1.79 b
Domo + INA	1.18 c
Gisilba NF	1.33 a
Gisilba	0.84 a
Gisilba + INA	0.08 b

NF - not frozen.
INA - plants sprayed with ice nucleating bacteria.
Means in the same column followed by the same letter are not significantly different.
Plants frozen 49 days after planting.

G. Determination of Ice Nucleators

In order for plants to freeze there must be ice nucleators either in the air or present on the leaves of plants. If there are no ice nucleators present, plants will supercool and escape the frost. Under conditions of a radiation frost, there is little evidence of ice crystals in the air which would cause plants to freeze. Recently, much research has centered on certain strains of bacteria, namely, **Pseudomonas syringae** and **Erwinia herbicola**. These bacteria are special in that they initiate freezing in plants at -2 to $-3^{o}C$. Plants grown under sterile conditions remain unfrozen (supercooled) to temperatures as low as -8 to $-10^{o}C$. Thus, these plants do not freeze and escape the frost. We have tested plants over the last three years for the presence of ice nucleating bacteria. Two species of bacteria were identified which had ice nucleating activity. The species were **Pseudomonas syringae** and **Erwinia herbicola**.

Plants were collected from the field throughout the growing season to determine if there were ice nucleators present on their leaves. Leaves were frozen in water in test tubes to determine the temperature the leaves froze at. Distilled water does not freeze until cooled to -13° to -15°C. If there are ice nucleators present in the leaves, they will cause water to freeze. This is used as an index of ice nucleators.

Leaves were washed in sterile phosphate buffer (pH 7.0) to determine if there was ice nucleating bacteria present. Droplets of buffer were placed on an aluminum block contained in a freezer at -2°C and then cooled at 2°C/hour. The number of drops which froze were recorded at 0.5°C intervals.

Wheat leaves collected early June did not freeze until -5.5°C. However, as the plants approached maturity their leaves froze progressively at warmer temperatures. At the beginning of August, the leaves froze at -4.5°C, whereas at the end of August the heads froze at -3.5°C. The wash from wheat leaves at the beginning of the season did not freeze until cooled to -7.5°C. However, as the plant matured, there were more ice nucleators present in the leaves. On August 7, the leaf wash froze at -5°C. Similar trends were observed for barley and oats, except that in August the plants froze at warmer temperatures than the wheat. On August 12, the leaves of wheat and oats froze at -2.5°C, in contrast to wheat leaves which froze at -4.5°C. The canola and mustard plants had a similar freezing pattern to the oat varieties.

Plants in 1986 tended to freeze at warmer temperatures in the summer and fall than plants collected in 1984 and 1985. A probable reason for this was the wet cool fall of 1986. Bacterial population with ice nucleating ability increased drastically from spring to fall, much more so than was observed in 1984 and 1985. Thus climatic factors have a strong influence on bacterial ice populations. Oats, on average, had the highest population of ice nucleating bacteria. Tobin tended to have high populations of ice nucleating bacteria than Westar. The main ice nucleating bacteria was **Pseudomonas syringae** which caused freezing at -2 to -3°C. **E. herbicola** was found in lesser quantities and was also less effective in initiating freezing.

Research to control bacterial populations demonstrated that both $CuSO_4$ and $ZnSO_4$ were very effective in reducing bacterial growth on a defined media. Plants in the field were sprayed with antibiotics, $CuSO_4$ and $ZnSO_4$ on August 11, 1986. These plants were then screened for ice nucleating active bacteria and the ability of the plants to supercool. On average, the bacterial populations were reduced and the plants supercooled to a lower temperature. However, much future research is required to determine the most effective date to spray, the most effective bacteriocide to be used and the use of antagonistic bacteria. Naturally occurring antagonistic bacteria have been identified which reduce the population of ice nucleating bacteria in plants.

H. Summary

1. Wheat is the most frost tolerant spring crop followed closely by barley, oats, flax, mustard and canola.

2. Spring plants grown under sterile conditions can be cooled at -8°C without freezing occurring in the plant.

3. Spring plants do not contain effective intrinsic ice nucleators in the temperature range of 0 to -8°C.

4. Spring plants cooled to -8°C show no apparent signs of injury provided they do not freeze.

5. Canola plants in the cotyledon stage are very frost sensitive (-2 to -3°C). At the 4 to 6 leaf stage they are able to tolerate a frost of -4°C.

6. The flowers and pods of canola are more sensitive to freezing than the leaves.

7. Ice nucleating active bacteria, *P. syringae* and *E. herbicola*, play an important role in causing plants to freeze in Western Canada.

The Effect of Growth Regulators on the Winter Survival of Seven Winter Wheat Cultivars

B.J. O'Connor, L.V. Gusta, M.J. Reaney and D. Tompkins

This study was initiated to determine if less hardy high yielding cultivars such as Monopol, Cimmaron and Houser can be overwintered by the use of growth regulators.

Seven winter wheat varieties of various hardiness levels were seded into rape stubble and sprayed on two dates in the falls of 1985 and 1986. The concentration of growth regulators were as follows: Cycocel extra 0.5 and 1.0%; Mefluidide 0.05 and 0.10%; Bayleton 0.1 and 0.2% and Terpal C 0.5 and 1.0%. Citowelt plus at a final concentration of 0.1% was added to all growth regulators to aid in uptake.

Plant samples were collected in the spring from three reps. Controlled freeze tests were conducted to determine the plants' cold hardiness level. Initial results show the effect of the growth regulators on increasing the cold hardiness level of winter wheat crown is greater in the less hardy varieties such as Cimmaron and Houser (Table 1).

Table 1. The Cold Hardiness Levels of Winter Wheat Crowns Sprayed with Mefluidide in April 1986.

Growth Regulator	Spray Rate (%)	Spray Date	Cultivars Cimmaron	 Houser	 Norstar	 Norwin
			LT_{50}'s (°C)			
Mefluidide	0.05	Early	-12	-12	-14	-13
	0.10		-12	-13	-13	-13
	0.05	Late	-11	-13	-13	-14
	0.10		-11	-11	-14	-12
Control			-10	-10	-13	-13

The Mefluidide and the Bayleton spray treatments show higher hardiness levels than the Cycocel extra and Terpal C treatments. These trends are being followed in our initial results from samples collected in November from the 1986 fall planting.

Effects on plant development and grain yield are also being determined.

L.V. Gusta, M.J. Reaney and B.J. O'Connor

Abstract

The effect of abscisic acid (ABA) on the frost tolerance of spring crops, Norstar winter wheat and cell suspension cultures was determined. ABA applied as a foliar spray had no significant effect on Ketepawa wheat, Harrington barley, and Cascade oats growing at either 20°C day and 10°C night or at 15°C day and 10°C night. The frost tolerance of plants growing at the cool temperatures was 4 to 2°C greater than plants grown at the warmer temperatures. Ketepawa was the most frost tolerant cereal. ABA slightly increased the frost tolerance of Westar and Tobin canola and Noralta flax. ABA applied as a foliar spray increased the frost tolerance of Norstar winter wheat by 2°C. ABA, injected into the crown of Norstar with a syringe, increased the frost tolerance by 9°C. It appears that although ABA can induce frost tolerance the method of getting ABA to the target cells must be improved.

SCIENTIFIC RESULTS

Introduction

Nature and Scope of Problem

Each year in western Canada millions of dollars are lost in crop production due to untimely frost in the spring and in early fall. Widespread killing frosts occurred on August 13, 1979, August 23, 1982 and August 26, 1985. Localized killing frosts occur almost every year in western Canada. In the northern areas, late maturing high yielding varieties such as Westar rape cannot be grown because of fall frosts. Tobin rape is often sown late to escape spring frosts. In 1985, over 50% of the canola crop in western Canada graded sample due to fall frosts. Green seeds, produced as a result of frosts, must be bleached to produce number one oil for export to Japan. This costs the crushers an additional 25 to 30 dollars for each metric ton of oil. The oil produced from frozen seeds is dark in color. Frosted wheat is less desirable to the millers and is often graded feed.

If the frost resistance of spring crops could be increased by only 2 to 3°C, this would make the difference between a good high quality crop and a crop failure.

This research project was to determine if the frost tolerance of crops could be increased by naturally occurring hormone abscisic acid (ABA). Research in our laboratory demonstrated that ABA increased the freezing tolerance of bromegrass cell suspension cultures from -3°C to -40°C in seven days at 25°C.

OBJECTIVES: To determine if the frost hardiness of economic crops can be increased by the application of abscisic acid.

To determine the most effective way of applying abscisic acid or related compounds to plants to increase their frost hardiness.

To determine how abscisic acid increases frost hardiness.

Materials and Methods

Whole Plant Studies

Cultivars of spring cereals namely Ketepawa, Harrington and Cascade and cultivars of canola namely Westar and Tobin and Noralta flax and the winter wheat Norstar were grown in controlled environment chambers at either 20°C day and 10°C night or at 15°C day and 10°C night with a 16 hour photoperiod. Plants 27 to 29 days old were sprayed with a 7.5×10^{-5} molar solution of ABA dissolved in water containing 0.5% Agral 90. The plants were tested for frost tolerance five days after spraying by subjecting them to a controlled frost of -3, -4, -5, -6, -8, -10 and -12°C in our modified freezers. After 1 to 4 days, the plants were rated for frost injury and after 1 week the plants were rated for recovery. All treatments were replicated four times in a complete randomized block design.

Plants of Norstar winter wheat were sown in a controlled environment chamber at either 20°C day and 10°C night or at 15°C day and 10°C night with a 16 hour photoperiod. At the two to three leaf stage, the plants were sprayed with a 7.5×10^{-5} molar solution of ABA. Four penetrants and a surfactant were used to increase ABA uptake. The penetrants used were DMSO (10% V/V), toluene (0.1% V/V), glycerol (20% V/V) and PEG-20M (25% W/V). The surfactant was triton X-100 (0.05% V/V). Control solution without surfactant, penetrant and ABA were also tested. Plants were sprayed 16, 18 and 20 days after planting and transferred to a controlled environment chamber.

All plant parts 3.5 cm above and immediately below the base of the crown were removed. Twenty-five crowns from each treatment were frozen in six centimeter aluminum tins. The plants were cooled to -4, -6, -8 and -10°C at a rate of 2°C per hour. Following the freeze-thaw cycle, the plants were replanted in a mixture of soil:peat:vermiculite and then transferred to a greenhouse for three weeks to determine survival.

Norstar winter wheat at the three leaf stage, growing in controlled environment chambers at 20°C day and 16°C night, were injected with 7.5×10^{-5} ABA and 2% sucrose with a syringe. Cold hardiness of the crowns was determined 9 days after treatment. The plants were then transferred to 2°C and the cold hardiness determined after 14 days.

Cell Suspension Studies

The effect of ethanol, tissue culture innoculum size on the ABA induction of cold hardiness in bromegrass and alfalfa cell suspension cells was determined. Cells were frozen as described by Chen and Gusta. Viability was determined by TTC reduction, fluorescien diacetate staining and by regrowth.

Results

Frost Tolerance of Plants Grown at 15°C Day and 10°C Night

Plants grown at 15°C day and 10°C night were more frost tolerant than plants grown at 20°C day and 10°C night (Table I compared to Table II). Ketepawa grown at 15°C and 10°C night was 4°C more frost tolerant than plants grown at 20°C day and 10°C. Similarly, the frost tolerance of Harrington barley and Cascade oats increased 2° and 3°C, respectively. The frost tolerance of the canolas and Noralta flax at the cool temperature increased by 2°C and 1°C, respectively.

Ketepawa wheat grown under cool conditions survived a frost of -8°C without apparent signs of injury. These plants grew to maturity to produce plants similar to the controls. Harrington barley did not frost acclimate to the same extent as Ketepawa wheat and could tolerate a frost of -6°C. In some of the Harrington barley plants frosted to -6°C, the head became trapped in the flag leaf. This was also observed in wheat plants frosted to -10°C. Cascade oats was similar in frost tolerance to Harrington barley. ABA did not increase the cold hardiness of these cereals.

Both Westar and Tobin canola grown at 15°C day and 10°C night survived a frost of -6°C but were killed at -8°C. In some cases, new shoots were produced at the base of the plant which matured much later than the controls. Canola plants do have the capacity to regenerate at the base provided it is not also killed. The ABA spray only slightly increased the frost tolerance of the Westar plants.

Noralta flax grown at 15°C day and 10°C night survived a frost of -5°C, were injured at -6°C and killed at -8°C. ABA had only a slight effect on frost tolerance.

Frost Tolerance of Norstar Leaves

Norstar winter wheat plants grown at either 20°C day and 10°C night or at 15°C day and 10°C night were sprayed with 7.5×10^{-5} ABA at the two to three leaf stage. The leaves of Norstar plants grown at 20°C could tolerate a frost of -8°C. At -10°C only the ABA treated plants survived whereas the control plants were killed. Plants grown at 15°C day and 10°C night were more frost tolerant than the 20°C day and 10°C night plants. These plants survived a frost of -10°C. There was no effect of ABA at these temperatures. These results also demonstrate that the leaves of winter wheat plants are more frost tolerant than spring wheat plants grown at the same temperature.

Frost Tolerance of Norstar Crowns

Four penetrants, DMSO, toluene glycerol and PEG-20M and the surfactant Triton X-100 were tested to determine if they increased ABA uptake by the leaves of Norstar wheat. None of the above chemicals in combination with ABA increased the frost tolerance of Norstar crowns.

Injection of ABA

The crowns of Norstar winter wheat plants growing at 20°C day and 16°C night were injected with a solution of 7.5×10^{-5}M ABA or 7.5×10^{-5}M ABA plus 2% sucrose. The control plants were injected with water. The frost hardiness of the control plants was -3°C (Table IV) whereas the frost hardiness of the crowns injected with ABA was -11°C. Crowns receiving only 2% sucrose were frost hardy to -7°C.

Plants injected with ABA, ABA plus sucrose and sucrose alone were transferred to 2°C for two weeks. Control plants survived a frost of -12°C, plants injected with sucrose survived -16°C, plants injected with ABA survived -14°C and plants injected with ABA plus sucrose survived to -15°C.

Factors Affecting ABA Frost Induction in Cell Suspension Cultures

Abscisic acid has been demonstrated to induce hardening to freezing temperatures in plants in tissue culture. Chen and Gusta demonstrated that tissue capable of cold hardening increased in hardiness upon treatment with ABA at non-hardening temperatures. However, application of ABA to plants has failed to increase hardiness or has produced only limited hardiness. This study was conducted to determine the factors which limit the ABA induced hardening of cells at non-hardening temperatures. The effect of ethanol, culture size, changes in culture medium due to growth of cells and stage of growth were investigated in relation to hardening.

Bromegrass cells at a non-hardening temperature of 25°C were frost tolerant from -7 to -11°C over a 7-day period (Table V). A 2 g innoculum of cells treated with 7.5×10^{-5}M ABA had an LT_{50} of -15°C after 2 and 4 days of treatment. After the seventh day, the ABA treated cells survived -60°C. If ethanol was used to dissolve ABA, the bromegrass cells only attained a frost tolerance of -35°C after 7 days. A 6 g innoculum of cells did not attain the same level of freezing tolerance as a 2 g innoculum. After 5 days of ABA the cells were frost tolerant to -25°C, but on the seventh day the cells were reduced to a frost tolerance of -12°C.

A time course study on the freezing resistance of alfalfa cells treated with and without ABA revealed that both cultures attained a similar level of frost tolerance (-20°C) after 3 days. Thereafter the cells lost freezing tolerance, however, the control cells lost freezing resistance at a faster rate than the ABA treated cells (Table V).

Medium pH Changes

The initial pH of the culture medium was 5.8. After 2 days of growth of a 6 g initial innoculum of bromegrass culture, the pH of the medium decreased to 4.3 in the control and to 4.4 in the ABA treated cells. After 5 days of culture, the pH of the medium increased to 6.7 and 6.9 for the control and ABA treated cells. A 2 g innoculum of bromegrass cells had a less pronounced effect on the pH of the medium as compared to a 6 g innoculum. For a 2 g culture treated with ABA, the pH of the medium increased to 6.3 in 1.5 days and decreased to 5.2 after 6 days. After 10 days, the pH of the medium had increased to 5.8. In control cultures, the pH declined to 4.7 after 3.5 days and then increased to 5.7 after 7 days.

Discussion

Unseasonal frosts are one of the major limiting factors for crop production in western Canada. Potential export markets are limited due to the uncertainty of crop production. If canola plants are frozen prior to seed ripening the seeds do not mature properly and remain green. Green oil, produced from these seeds, cannot be marketed to Japan. Frosted wheat results in poor milling quality. Seed produced from frosted crops has a low germination rate and does not pass seed registration. Presently little research is conducted in western Canada on how to improve the frost tolerance of economic spring crops.

Abscisic acid (ABA), a naturally-occurring plant hormone, has been demonstrated to enhance the frost resistance of plant cells growing in tissue culture. However, limited success has been achieved when ABA is applied as a spray. This research was to determine if ABA would increase the frost tolerance of spring wheat, barley, oats, canola and flax and also to determine what effect it had on Norstar winter wheat.

ABA had little effect on the frost tolerance of Ketepawa wheat, Harrington barley and Cascade oats. There was a slight improvement in the frost tolerance of Westar and Tobin rape and Noralta flax. An important finding of this study was that plants growing at cool temperatures (15°C day and 10°C night) had more frost tolerance than plants growing at 20°C day and 10°C night. Plants growing at cool temperatures were 4 to 1°C more frost tolerant than plants growing at warm temperatures. Ketepawa spring wheat was the most frost hardy of the spring crops tested. ABA applied as a spray to Norstar winter wheat growing at 20°C day and 10°C night increased the frost tolerance by 2°C. However, ABA had no effect on the frost tolerance of winter wheat growing at 15°C day and 10°C night. Norstar winter wheat leaves were 2°C more frost tolerant than Ketepawa wheat growing at 20°C day and 10°C night. These results suggest that winter by spring crosses to produce spring types may provide additional frost tolerance.

The frost tolerance of Norstar winter wheat crosses increased 9°C if ABA was injected into the crowns with a hypodermic needle. These results demonstrate that ABA does increase the frost resistance of plants. Therefore sprays of ABA are ineffective. Several reasons why sprays of ABA are not effective are: ABA is degraded by the enzymes in the leaves of the plant; ABA is not translocated to the crown of the plant; and/or light and microorganisms on the leaf surface inactivate ABA.

ABA is not water soluble and therefore must be first dissolved in a small quantity of ethanol. Ethanol inhibits ABA from inducing frost hardening in cell suspension cultures. The ratio of ABA to the size of the cell culture innoculum is important for the induction of ABA. A large innoculum of bromegrass cell cultures did not cold harden to the same level as a small innoculum.

In summary, ABA does have potential for increasing frost tolerance. However, the limiting factors are: how ABA can be applied to ensure that it gets to the proper sites of induction without being degraded by light, microorganisms and the plant's enzyme system.

Table I. The Effect of ABA on the Frost Tolerance of Cereals, Canola and Flax Grown at 20°C day and 10°C Night.

	% Plants Alive					
Treatment	Ketepawa	Harrington	Cascade	Westar	Tobin	Noralta
Control	100	100	100	100	100	100
-3°C	100	100	100	100	100	100
-3°C plus ABA	100	100	100	100	100	75
-4°C	60	100	20	80	80	100
-4°C plus ABA	40	40	0	80	80	100
-5°C	40	0	0	0	0	80
-5°C plus ABA	20	0	0	30	20	60
-6°C	0	0	0	0	0	0
-6°C plus ABA	0	0	0	0	0	20

Table II. The Effect of ABA on the Frost Tolerance of Cereals, Canola and Flax Grown at 15°C Day and 10°C Night.

	% Plants Alive					
Treatment	Ketepawa	Harrington	Cascade	Westar	Tobin	Noralta
Control	100	100	100	100	100	100
-3°C				100	100	100
-3°C plus ABA				100	100	80
-4°C	100	100	100	100	100	80
-4°C plus ABA	100	100	100	100	100	80
-5°C	100	100	100	100	100	80
-5°C plus ABA	100	100	100	100	100	100
-6°C	100	100	100	100	100	60
-6°C plus ABA	80	60	80	100	100	80
-8°C	100	0	20	0	0	0
-8°C plus ABA	80	20	0	20	0	15
-10°C	40	0	0	0	0	0
-10°C plus ABA	60	0	0	0	0	0

Table III. The Frost Tolerance of Norstar Winter Wheat Leaves Sprayed with ABA.

Treatment	% Plants Alive	
	20°C Day and 10°C Night	15°C Day and 10°C Night
Control	100	100
-6°C	100	100
-6°C plus ABA	100	100
-8°C	80	100
-8°C plus ABA	80	100
-10°C	0	100
-10°C plus ABA	80	100
-12°C	0	0
-12°C plus ABA	0	0

Table IV. Frost Tolerance of Norstar Crowns Injected with ABA, Sucrose and ABA Plus Sucrose.

Treatment		Temp (°C)	Time After Injection (days)	LT_{50} (°C)
ABA	Sucrose			
-	-	20/16	9	-3
-	+	20/16	9	-7
+	-	20/16	9	-11
+	+	20/16	9	-12
-	-	2/2	14	-12
-	+	2/2	14	-16
+	-	2/2	14	-14
+	+	2/2	14	-15

Plants treated with 7.5×10^{-5} M ABA or 2% sucrose.

Table V. The Effect of Innoculum Size and Ethanol on the ABA Induced Freezing Resistance of Bromegrass Cells.

	Frost Tolerance (°C)						
	Time (days)						
Treatment	0	2	3	4	5	7	10
Control	-7	-10	-7		-11	-7	
ABA (2g)*	-7		-17	-18		-60	-60
ABA (6g)*	-7	-16	-20		-25	-11	
ABA + Ethanol** (2g)	-7	-14		-17		-33	-33

* Innoculum size
** 20 mm ethanol

Table VI. The Effect of 1.0×10^{-4} M ABA on the ABA Induced Freezing Resistance of Alfalfa Cells.

	Frost Tolerance (°C)							
	Time (days)							
Treatment	0	1	2	3	4	5	7	14
Control	-5	-16	-19	-23	-17	-17	-17	-2
ABA	-5	-16	-18	-20	-23	-22	-20	-12

Cold Acclimation of Winter Cereals: Wheat, Rye and Triticale

Monika MacHutchon and L.V. Gusta

A considerable effort has been made in the past to determine the factors involved in cold acclimation of winter hardy cereals. This research has led to the expansion of winter wheat across the Canadian prairies. However, the inability to produce new hardier lines of winter wheat by traditional plant breeding methods has led many researchers to seek alternatives. Current research in progress has been designed to elucidate some of the basic cellular adaptations of winter hardy cereals during a period of cold temperature stress. This project has 4 major aspects:

1. Field survival of 7 cultivars of winter wheat, 12 experimental lines of triticales and 2 cultivars of fall rye at Saskatoon, Sask. and Lacombe, Alta.

2. Date of seeding evaluation on 2 selected lines each of winter wheat, fall rye and winter triticale.

3. Growth room studies on the acclimation potential of winter cereals under artificial conditions.

4. A biochemical and physiological investigation into the process of cold acclimation of 2 lines each of winter wheat, fall rye and winter triticale.

MATERIALS AND METHODS: Seed of winter wheat was obtained from North Dakota State University for use in field survival evaluation. Siouxland, Agassiz, Roughrider, Bighorn, Rose and a North Dakota selection ND8002 were seeded into canola stubble at Saskatoon. Norstar was included as the hardy check cultivar.

Seed of 12 experimental lines of triticale were obtained from the Alberta Agriculture Research Station at Lacombe and was seeded into canola stubble at Saskatoon. The triticales and Norstar winter wheat were seeded into summerfallow at Lacombe to evaluate the hardiness of the cereals under different environmental conditions.

Three seeding dates at Saskatoon were used to determine the effect of the length of the acclimiation period on the level and duration of cold hardiness attained. Two representative cultivars and lines of winter wheat, triticale and fall rye were chosen based on their documented cold hardiness levels. Norstar and Siouxland winter wheats, Puma and Bulgarian Dwarf fall ryes and 81DE01015 and 79B189001 lines of triticale were used due to their superior and intermediate hardiness levels, respectively. Seeding dates of August 15, September 9 and September 25 were used. Seedlings were removed from the field on November 3, 4 and 5 in order to monitor changes in hardiness through the winter. Controlled freeze tests were run on seedlings from November of 1986 to April of 1987 in conjunction with biochemical and physiological tests.

Growth room studies using the 2 cultivars and lines of winter wheat, fall rye and triticale were initiated to compare acclimation under artificial conditions with field acclimation.

RESULTS: Preliminary results of artificial freeze tests up to February 1987 are presented in Table I.

Table I. LT_{50}* of winter wheat, fall rye and winter triticale for the first seeding date, August 15, 1986.

	LT_{50}			
	November	December	January	February
winter wheat:				
Siouxland (Sk)	-19	-19	-17	-17
Norstar (La)	-25	-21	-19	-19
Norstar (Sk)	-25	-21	-21	-19
fall rye:				
Bulgarian Dwarf (Sk)	-29	-29	-29	-23
Puma (Sk)	-31	-31	-31	-27
triticale:				
79B053 (La)	-15	<-11	<-11	<-9
79B189001 (La)	-19	-15	-11	<-9
79B189001 (Sk)	-23	-17	-15	<-11
81DE01015 (La)	-23	-19	-19	-17
81DE01015 (Sk)	-23	-19	-19	-19

*LT_{50} = temperature (°C) at which 50% of seedlings are killed.

The LT_{50} values were higher (i.e. warmer) for freeze tests performed on seedlings planted on the second seeding date (Sept. 9, 1986) and higher again for seedlings tested from the third seeding date (Sept. 25, 1986). For example, seedlings of Puma rye decreased in hardiness (based on artificial freeze tests) by February in accordance with the date of seeding; from -27, to -23, to -19 for the 1st, 2nd and 3rd seeding dates, respectively.

The triticale line 81DE01015 exhibited both good hardiness and hardiness for an extended period through the winter. However, the hardiness level decreased rapidly with seeding date, from -19 for seedlings planted Aug. 15, to -17 for seedlings planted Sept. 9, to less than -11 for seedlings planted Sept. 25 (February freeze test results).

Morphological analyses of seedlings obtained from Lacombe and Saskatoon revealed a difference in seedling size, number of tillers, crown depth and seeding leaf number. Seedlings of winter wheat and triticale grown on summerfallow at Lacombe were large, robust and had up to 7 tillers in a compact rosette form after 9 weeks growth. Seedlings from Saskatoon were small, had either no or rarely 1 tiller, had fewer leaves and were of a more upright growth habit. Only in the triticale line 79B189001 grown at Saskatoon was the % crown moisture content significantly lower than all other material, including line 79B189001 grown at Lacombe.

Preliminary data on biochemical and physiological parameters are incomplete at present. The activity of the enzyme sucrose phosphate synthetase is being monitored to determine the effect of both the rate of sucrose formation during acclimation and the amount of sucrose accumulated at maximum hardiness levels.

Experiments to determine root initiation after a freeze test are in progress.

SUMMARY: The preliminary data obtained to date do not allow conclusions to be drawn on genotypic differences within the cereals being studied nor on the extent and nature of the environmental effect on the expression of the cold hardiness potential of the experimental lines of triticale. It is anticipated that an understanding of basic cell, tissue and plant responses to cold stress will enhance both plant breeding and biotechnological selection and development of hardier and economically attractive winter cereals.

Mechanisms by which ABA Increases Plant Cold Hardiness

A.J. Robertson, M. Ishikawa, M.J. Reaney and L.V. Gusta

Plants require three to four weeks at 3°C temperatures to achieve maximum hardiness levels. In contrast, plant cell suspension cultures treated with 75 M abscisic acid (ABA) can increase in cold hardiness from -5°C to -35°C within 7 days at 20°C (Chen and Gusta, 1983, Plant Physiol. 73: 71). The control of frost hardiness in plants at warm temperatures may be used to avoid unseasonal frosts. Winter wheat plants grown on sterile agar supplemented with 75 M ABA at 20/16°C for 9 days increased in hardiness by 11°C. However, ABA sprays applied to winter wheat plants under natural conditions increased hardiness levels only 1 or 2°C. Synthetic growth regulators or ABA analogues not subject to rapid degradation under natural conditions are currently being tested for hardening activity.

Bromegrass suspension culture cells treated with 75 M ABA were morphologically typical of hardy cells. For example, ABA treated cells had thickened cell walls, numerous small vacuoles, and increased numbers of lipid bodies and starch granules. ABA treatment at 25 and 30°C induced higher levels of hardiness in shorter time periods than 15 and 20°C treatment temperatures. Light had no effect, but high initial inoculum densities and ethanol inhibited the degree of freezing resistance attained (Reaney and Gusta, 1987). Increased media nitrogen decreased the freezing tolerance of both control and ABA treated cells, whereas media sucrose, potassium and phosphate had no effect.

Protein changes occurring during the development of freezing resistance were analyzed in alfalfa (Robertson and Gusta, 1986) and bromegrass (Robertson et al. 1985, Gusta et al. 1987) cell suspension cultures. This has resulted in the identification of proteins putatively involved in adaptation to low temperature growth, proteins induced and regulated by ABA and proteins correlated with increased freezing resistance. Several proteins were induced (19, 21 and 47 kD) within 30 minutes of ABA treatment at 23°C. These proteins are suspected to be involved in the regulation and/or development of hormone induced changes. Several proteins accumulating after both ABA and low temperature induced freezing resistance were also identified (25, 30, 72, 200 kD). The 25 and 30 kD proteins co-fractionated with microsomal membrane fractions and were most correlated with increased expression of freezing resistance. Attempts are currently being made to localize, purify and functionally characterize the 30 and 25 kD membrane associated proteins.

Bromegrass cells treated with 75 M ABA have increased resistance to heat, salt and osmotic stresses. Comparative two-dimensional SDS PAGE of total cell protein isolated from control cultures and those treated with 75 M ABA, -5 bar PEC, 68 mM NaCl at 25°C for 10 days was performed. Three polypeptides (43, 45 and 47 kD) with apparent P_I values between 6.83 and 6.30 which were increased by salt and osmotic stresses were identified. Cell suspension cultures treated with 75 M ABA induced the *de novo* synthesis of seven proteins (31, 26, 22, 24, 82, 75, 43 kD) not detected in control cultures after 10 days growth. However, several other proteins were increased dramatically by ABA treatment (30, 41, 38) including proteins increased by salt and osmotic stresses (43, 45, 47 kD). Several proteins were also inhibited by ABA treatments. In addition, a 30 kD membrane associated protein increased by exogenous ABA treatment was also found to be increased by low temperature stress.

1.1.1 ABA induced freezing tolerance in bromegrass suspension cultures and winter wheat plants

Bromegrass cell suspension cultures treated with 75 µM ABA increased in cold hardiness from -5°C to -35°C within 7 days. Plants require three to four weeks at 3°C temperatures to achieve maximum hardiness levels. However, application of ABA sprays to winter wheat plants increased their hardiness levels only 1 or 2°C. Hardiness levels increased from -3°C to -12°C within 9 days when plants were grown on sterile agar supplemented with 75 µM ABA at maximum day/minimum night temperatures of 20/16°C. At 2°/2°C temperatures ABA treatment was less effective in increasing hardiness levels over that attained by control plants.

1.1.2 ABA and low temperature effects on the morphology of plant cells.

Light, thin section and freeze fracture microscopy of bromegrass suspension cultures grown at low temperatures and in the presence of ABA were performed. Low temperature and ABA treatment showed an increase in the particulate nature of the cytoplasm in light microscope and thin section electron microscope studies. An increased frequency of lipid bodies and numerous small vacuoles were noted in ABA treated cultures. Freeze fracture analyses showed fewer particles per unit area on the E fracture face of the plasma membrane in low temperature hardened bromegrass cells. Differences in ABA treated cultures were less obvious and more variable. The source of variability was suspected to be due to culture conditions (age, temperature of ABA treatment, light effects, etc.). Therefore, a rigorous study into the variability associated with ABA induced hardening of bromegrass suspension cultures was initiated. This was a necessary deviation from initial objectives, since reproducible culture conditions were required for molecular analyses.

1.1.3 Effects of culture conditions on ABA-induced freezing tolerance.

The effect of temperature, light, inoculum size, ethanol, and nutritional status on ABA induced freezing resistance in bromegrass cell suspension cultures was investigated. ABA induced cold hardiness had an optimum between 25°C and 30°C (LT_{50} = -30°C to -35°C), whereas temperatures of 15 and 20°C resulted in hardening to only -15 to -17°C. No significant differences in ABA induced cold hardiness were detected when cells were grown in light or in darkness. Initial cell inoculum densities were found to affect the degree of freezing resistance attained. Optimum freezing tolerance was observed when cultures were established with 2 grams or less fresh weight inocula. In addition, the presence of 10 mM ethanol in the ABA containing medium inhibited freezing tolerance. The cold hardiness of control cultures was not affected by ethanol. Media nitrogen in the form of NH_4^+ and NO_3^- generally decreased the freezing tolerance of cultured cells both in the presence and absence of ABA. Sucrose, potassium and phosphate when added to the medium did not significantly affect the freezing tolerance of control or ABA treated cells.

A series of viability tests were compared to determine the most reliable method for determining freezing resistance. The LT_{50} values obtained from regrowth, amino acid leakage (A_{280}) and fluoresceine diacetate staining (FD) were in agreement. The triphenyl tetrazolium chloride reduction (TTC) method overestimated cold hardiness levels by a few degrees compared to other methods. However, the TTC test was reliable and most convenient for estimating freezing resistance of cell suspension cultures.

1.1.4 Identification of protein changes during ABA and low temperature induced hardening.

Protein changes were identified by monitoring protein synthesis in bromegrass cells induced to cold harden by ABA and low temperature. Protein synthesis was initially monitored by equilibrium labelling with [^{14}C]-leucine, and at later times by pulse labelling with [^{35}S]-methionine. The uptake, incorporation and turnover of [^{14}C]-leucine into bromegrass suspension cultures grown at 3°C and 23°C in the presence and absence of ABA was measured after .5, 1, 2, 4, 8, 12, 24, 36, 42, 60 and 96 hours. Treatment with 75 µm ABA had no measurable effects on uptake at 3°C, but caused an initial lag between 0.5 and 2 h time periods at 23°C. ABA treated cells at 23° accumulated similar levels of [^{14}C]-leucine in 36 h as did controls grown for 24 h. Cold treated cells accumulated leucine slower, but to much higher levels than cells grown at 23°C after 24 hours of growth. Incorporation of [^{14}C]-leucine into TCA precipitable material was linear for 8 hours at 23°C, control cultures accumulating 30% more label than ABA treated cultures in this time period. After 24 hours, the cold treated material accumulated approximately 45 percent more label per mg dry weight than cells grown at 23°C.

Both one and two-dimensional SDS-PAGE of total cell protein fractions from [^{14}C]-leucine and [^{35}S]-methionine labelled bromegrass cells were performed. Most of the major proteins detected at 23°C were synthesized at later time periods at 3°C. However, some proteins were induced by low temperature treatment, whereas others were inhibited. Comparative electrophoretic analysis of [^{14}C]-leucine labelled protein detected the initial synthesis of 19, 21 and 47 kD proteins in less than 8 hours after exposure to exogenous ABA at 23°. Proteins in the 20 kD range were also synthesized at 3°C. In addition, a 31 kD protein band was enriched in freezing resistant ABA treated cultures after 36 hours growth at both 3 and 23°C. Quantitative analysis of two dimensional gels confirmed the enrichment of the 31 kD protein at 3°C. Two dimensional analyses also resolved a 72 kD protein enriched in ABA treated cultures and identified three proteins (24.5, 47 and 48 kD) induced by low temperature growth.

1.1.5 Subcellular localization of ABA and low temperature induced proteins.

Electrophoretic analyses of total cell, soluble, microsomal, cell wall and extracellular proteins were performed on both alfalfa and bromegrass cell suspension cultures growth at 3°, 20° and 25° in the presence and absence of ABA. These analyses were performed on proteins extracted from four to six day old ABA and low temperature grown cells. After 6 days of growth high levels of freezing resistance were expressed in ABA treated cultures. Proteins accumulating after ABA and low temperature treatments were characterized by Coomassie blue, periodic acid Schiff, concanavalin A horse-radish peroxide bridge staining, silver staining and fluorography.

Proteins in extracellular fractions from ABA and low temperature grown alfalfa cells had decreased electrophoretic mobilities, lacked a 190 kD glycoprotein and had reduced amounts of four other polypeptides. These observations implied that ABA and low temperature grown cultures are either more resistant to protein loss during growth or that secretory processes are inhibited by ABA and low temperature treatments. These observations suggest that the cell wall and/or plasma membrane of both ABA and low temperature treated cells is altered. The shift in electrophoretic mobilities of both ABA and low temperature grown extracellular proteins reflects possible modification of extracellular proteins during the development of freezing resistance. The nature of the modification(s) is not understood and requires elucidation. Shifts in electrophoretic mobilities of bromegrass cell protein from low temperature grown cultures were also observed.

Analyses of total alfalfa cell protein identified a 42 kilodalton protein enriched in both ABA and low temperature treated cells. Several proteins increased or induced by ABA treatment were identified in the extracellular (12.5, 35 to 15 kilodaltons), total cell and cell wall (24 kilodalton) and soluble (20, 37 and 41 kilodaltons) fractions. The 42 kilodalton protein is of interest in relation to freezing resistance. However, other protein changes may be related to ABA metabolism and have no direct involvement in the expression of freezing resistance.

Extracellular protein fractions from control, ABA treated and low temperature grown bromegrass cultures were compared to those of alfalfa cell cultures. Coomassie blue staining identified eleven major polypeptide bands and silver staining 28 bands in control culture media. Most of the extracellular proteins bound concanavalin A, indicating that the majority of the extracellular proteins are glycoproteins or proteoglycans. All polypeptides were reduced in relative abundance in ABA treated cultures with the exception of 22 and 27 kD polypeptides. The 22 and 17 kD polypeptide did not bind concanavalin A or react with periodic acid Schiff. The 22 kD and 17 kD extracellular proteins were either not detectable or present in very low amounts in the extracellular fractions of suspension cultures grown in the absence of ABA. Further analyses of the 22 and 17 kD proteins induced by ABA have failed to correlate these proteins with freezing resistance. It is suspected that the 22 and 17 kD proteins may be involved in ABA metabolism. Amino acid analyses of extracellular fractions subjected to sephadex G15 column chromatography suggests that the 22 and 17 kD ABA induced proteins are rich in arginine and lysine amino acids.

Protein fractions from total cell homogenates of control, ABA and cold treated bromegrass cultures were solubilized in 2% SDS with 5% v/v mercaptoethanol. Solubilized proteins were subjected to SDS PAGE to identify protein changes induced by ABA and low temperature treatments after 4 and 6 day growth periods. Coomasie blue staining detected four protein bands with apparent M_r values of 40, 30, 25, 22 and 20 kD enriched by ABA treatment and a 25 kD band induced by low temperature growth in total cell protein fractions.

Total cell homogenates were fractionated by differential centrifugation into a microsomal membrane fraction and a soluble fraction. SDS PAGE of soluble and microsomal membrane fractions indicated that the 30, 25 and 22 kD bands co-fractionated with the microsomal fraction and 40, 22 and 20 kD bands with the soluble fraction. Cell fractionation resulted in the resolution of 37, 45 and 200 kD proteins in soluble fractions of ABA treated cells. Two minor bands were also apparent in soluble fractions at 190 and 160 kD after low temperature treatments. Common proteins accumulating during ABA and low temperature induced hardening were identified at 25 kD in membrane fractions and 200 kD in soluble fractions.

Two dimensional SDS PAGE of microsomal membrane and soluble protein fractions from control, ABA and cold hardened cell cultures were also performed. Two-dimensional analyses of microsomal membrane fractions isolated form ABA treated cultures resolved a major polypeptide with an apparent M_r of 30 kD and an apparent P_I of 6.85. The 30 kD polypeptide was detectable in control cultures, dramatically enriched in ABA treated cultures, but increased to a lesser extent in low temperature hardened cells. Recent quantitative analyses of two dimensional electrophoretograms from low temperature hardened bromegrass cultures has confirmed the enrichment of the 30 kD polypeptide over control levels. The low temperature hardened cultures consistently showed less hardiness than cultures hardened by ABA at 20-25°C temperatures.

Extensive analyses of protein changes occurring during the development of freezing resistance by low temperature growth and by ABA treatment at non hardening temperatures has been performed. This has resulted in the identification of proteins putatively involved in adaptation to low temperature growth, proteins induced and regulated by ABA, and proteins correlated with increased freezing resistance. Several proteins were induced (19, 21 and 47 kD) less than 1 hour after the exogenous application of ABA at 23°C. At this time period no significant increases in the level of freezing resistance had occurred. These proteins are suspected to be involved in the regulation and/or development of hormone induced cellular changes. Proteins accumulating after both ABA and low temperature induced freezing resistance were also identified (25, 30, 72,200 kD). The 25 and 30 kD proteins co-fractionated with microsomal membrane fractions and were most correlated with increased expression of freezing resistance. Attempts are currently being made to localize, purify and functionally characterize the 30 and 25 kD membrane associated proteins.

Problems have been encountered in isolating purified plasma membrane fractions from bromegrass suspension cultured cells exogenously treated with 75 μM ABA. The modified two-phase polymer procedure (Yoshida et al. 1983 Plant Physiol. 72: 105-114) resulted in low yields of plasma membrane when used for isolating plasma membranes from ABA treated cells. Thus, protein analyses have been performed on crude membrane fractions. Lipids have been extracted from low temperature and ABA treated cells, however, the quantitative analyses remains to be completed. Plasma membrane isolations and protein and lipid analyses are currently being attempted with winter wheat and bromegrass plant tissue after low temperature and ABA treatments.

1.1.6 Other Significant Achievements

Cell suspension cultures were also used to study the effect of ABA treatment on resistance to heat, salt and osmotic stresses. Bromegrass cells were treated with 75 μM ABA for various times prior to determination of heat, salt and osmotic stresses.

Heat tolerance was determined by triphenyl tetrazolium chloride reduction (TTC) after exposing control and ABA treated culture to 46°C temperatures for two hours. Bromegrass cells grown in the presence of 75 μM ABA for 84 hours at 25°C showed increased heat tolerance over control cells. ABA treated cells showed maximum heat tolerance after 10.5 days treatment.

The effect of ABA on inducing salt tolerance in suspension cultured cells was determined by subjecting ABA treated and control cells to .4M NaCl containing medium at 25°C for 18 hours. ABA treated cells were shown to have increased salt tolerance over control cells by TTC viability assays. Similar results were obtained in studies of osmotic stress tolerance using polyethylene glycol 5000 (PEG).

Comparative two-dimensional SDS PAGE of total cell protein isolated from control bromegrass cell cultures and those treated with 75 μM ABA, -5 bar PEG, 68 mM NaCl at 25°C for 10 days was performed. Approximately 375 to 400 polypeptides were visually compared after silver staining. Twenty one polypeptides were subjected to quantitative analyses using an LKB Laser Densitometer interfaced with an AT and T Computer system. Relative protein amounts were calculated using a 2400 GELSCAN XL Laser Densitometer software program (Copyright LKB Produkter AB, 1986). This resulted in the identification of three polypeptides (43, 45 and 47 KD) with apparent P_I values between 6.83 and 6.30 which were increased by salt and osmotic stresses. These proteins were also dramatically increased by exogenous treatment of bromegrass cells with 75 μM ABA. However, they were not found to be significantly increased by low temperature treatment.

Treatment of bromegrass cell suspension cultures with 75 μM ABA induced the synthesis of seven proteins (31, 26, 22, 24, 82, 75, 43 kD) not detected in control cultures after 10 days growth. However, several other proteins were increased dramatically by ABA treatment (29-30, 41, 38) including proteins increased by salt and osmotic stresses (43, 45, 47 kD). Several proteins were also inhibited by ABA treatment. In conclusion, all proteins associated with salt and osmotic stresses were increased by ABA. In addition, a 30 kD membrane associated polypeptide was increased by low temperature growth and dramatically increased by ABA treatment at non-hardening temperatures.

1.1.7 Scientific significance of results

The observation that ABA can increase the cold tolerance of winter wheat at non-hardening temperatures under sterile conditions is of significance. This makes it theoretically possible to harden plants to unseasonal frosts. These frosts cost the Canadian economy hundreds of millions of dollars annually. However, growth regulators with modes of action similar to ABA (or ABA analogues) not susceptible to bacterial and/or fungal degradation must be identified or synthesized. The identification or synthesis of such compounds would make field application practical.

The identification of proteins involved in the expression of freezing tolerance is of fundamental importance. The functional characterization of these proteins and the isolation of the genetic messages will allow the elucidation of the mechanism of freezing resistance. In addition, isolation and characterization of genetic messages involved in the expression of freezing tolerance may allow the construction of more frost tolerant varieties.

The observaton that ABA increases resistance to salt, osmotic and heat stresses in model systems greatly multiplies the potential economic importance of studying the mechanism by which ABA increases resistance to plant stresses.

1.4 Potential socio-economic benefits

This research project has made feasible the potential application of ABA analogues or comparable growth regulators to prevent unseasonal frost damage to valuable agricultural crops. In addition, the identification of proteins correlated with the expression of freezing tolerance will eventually allow the elucidation of the mechanism of freezing resistance. The functional characterization and the identification of the genetic messages coding these proteins should allow the construction and selection of more frost tolerant varieties.

The research described here should result in the consistent production of higher quality crops in the future. This will stabilize and expand valuable export markets for our agricultural grains. It will also serve to reduce the financial risks faced by farmers in producing plant products, besides stabilizing and enhancing our food production potential. The information gained from this study through the identification of proteins involved in the expression of freezing resistance should provide valuable information to plant molecular biologists and plant breeders in the design and selection of stress tolerant varieties. Chemical companies should also benefit from the production of products (ABA analogues, growth regulators) designed to enhance stress tolerance of agricultural crops.

The Effect of Plant Growth Regulators, Fungicides and Nitrogen on the Yield, Height of Norstar Winter Wheat

P.M.S. Bandara and L.V. Gusta

Four plant growth regulators (PGRs), Cycocel, Terpal C, Bayleton and Cerone were applied as follows: The PGRs, Cycocel, Terpal C and Bayleton at 23-24 and 32 of the Zadoks Scale and Cerone was applied at 32 and 45 of the Zakoks Scale. Four concentrations including untreated control were applied at each application date. Bayleton is a fungicide in addition to being a PGR. Two N levels were applied, lower N level (N_1) was 90 kg/ha and higher level (N_2), 45 kg/ha as ammonium nitrate at the 32 Zadoks stage in addition to N_1 rate. The treatments were assigned in split-split-nested design (PGRs as main plot, N levels as sub-plot, time of application as sub-sub-plot and rate of application was nested within the type of PGR). The plants were analyzed for yield, maturity, flag leaf area, flag leaf dry weight, total number of leaves, total plant dry weight, number of grains per spike,, effective tiller number per plant, number of heads per m^2, heights of 3 basal internodes, dry weight of basal part of culm (20 cm in length), harvest index and grain protein.

The application of Bayleton cause to increase the number of leaves per plant over the other PGRs. There were no significant increase on leaf number per plant due to the increase in N level.

No significant difference in either flag leaf area of flag leaf dry weight were observed among the PGR treatments.

Cerone caused to produce the shortest plants among the treated PGRs.

The effective tiller number per plant was significantly increased by application of Bayleton over the other PGR treatments.

Also, Bayleton caused to increase the number of grains/spike over that produced by other PGRs treated plots. The lowest number of grains per spike were observed from Cerone treated plots.

The application of PGR caused to reduce the plant height significantly. The application of CCC caused to increase the harvest index over the other PGRs. Cerone caused to reduce 1000 grains over the CCC applied treatment. The highest number of heads per m^2 was observed from CCC treated plot compared to other PGRs treated plots.

A significant reduction in plant height was observed from the late applied plots over the early application. However, the late application of PGR cause to reduce the number of grains per spike significantly over the early application.

The application of extra N over the recommended N dose did not influence on final plant height, effective tiller number or total heads number per plot However, it caused to increase the first internoded length significantly.

The Effect of 2,4-D and Terpal C on Winter Survival of Winter Wheat

L.V. Gusta and R. Holm

Spraying 2,4-D in the fall on winter wheat is a common practice of farmers. This study was initiated to determine the effect spraying 2,4-D alone and in combination with growth regulator Terpal C had on the cold hardiness of Norstar winter wheat crowns.

Terpal C was sprayed on the plants in the fall of 1985 at a rate of 1.0% (v/v) product. Two rates of 2,4-D were applied (6 oz and 12 oz). The 12 oz rate of 2,4-D consistently rated less hardy than the other treatments. The 12 oz rate in combination with Terpal C was consistently better than the Control and this was particularly evident at the 6 oz rate with Terpal C (Table 1).

Stabilizing the cold hardiness level of winter wheat throughout the critical winter months of January and February through spraying 2,4-D and growth regulators may help cultivars overwinter in areas of Saskatchewan which do not receive the 15 to 20 cm often necessary to survival.

Table 1. The Cold Hardiness Level of Norstar Winter Wheat Sprayed with 2,4-D and Terpal C.

	LT_{50}			
	December	January	February	March
Control	-16	-16	-10	- 7
Terpal C	-16	-15	-10	- 7
Terpal C + 6 oz 2,4-D	-16	-17	-19	-15
Terpal C + 12 oz 2,4-D	-16	-18	-16	- 9
6 oz 2,4-D	-16	-17	-16	- 9
12 oz 2,4-D	-13	-12	-10	- 7

D. WINTER CEREAL COOPERATIVE EXTENSION PROGRAM

D.B. Fowler - Co-ordinator

ABSTRACT

Information transfer has always been a high priority of the Crop Development Centre winter cereal research program. Research plots have been utilized for field demonstration purposes since the program was initiated in 1972. Starting in 1983, Provincial government (Agriculture Development Fund) support for these activities was supplemented by a grant from the Federal government's New Crop Development Fund (NCDF). A total of 12 research-demonstration sites were located throughout Saskatchewan in 1986. Farmer field days were held at each of these sites with the cooperation of local Agricultural Representatives. Completion of the NCDF contract and an inability to obtain new sources of funds will force a large reduction in this program in 1987. Further information transfer to the agricultural community was achieved through publication of 10 scientific papers, 3 chapters in books, 1 book, 10 proceedings papers, 28 conference presentations, 4 reports and newspaper articles and 21 radio, TV and newspaper interviews in 1986-87.

BACKGROUND AND OBJECTIVES

The winter cereal agronomy, plant breeding, physiology and genetics project contribution to the scientific basis for the development of winter cereals in Saskatchewan has been detailed in 76 scientific papers, 23 chapters in books, 2 books, 25 proceedings papers and 71 lectures to the scientific and farm community. Information transfer to the agricultural community has received high priority in this program - 8 technical reports have been prepared, 56 field days have been held, 53 short courses have been given, 47 reports and newspaper articles have been written, 20 television or visual productions prepared, and 165 radio, TV and newspaper interviews have been given in the last 6 years. The primary objective of this project has been to provide updated results of research on winter cereals to the Saskatchewan farmer in an understandable form in the shortest possible time.

EXPERIMENTAL METHODS

Every effort is made to cooperate with existing extension programs. This includes the Extension Division University of Saskatchewan, the Provincial Agricultural Representative network, Provincial Soils and Crops Specialists, Radio and TV Agricultural Reporters, Industry Extension personnel and the production and distribution of our own extension material. Where possible, research plots have been used for demonstration purposes.

RESULTS AND DISCUSSION

A detailed report on the winter wheat farm demonstration and research project is available on request. Reports on other activities associated with the winter cereal cooperative extension program can be found in the list of papers prepared and talks given section of this report. Other activities in this area during 1986-87 include.

Extension Activities

A. **Winter wheat field days** - 1986

Indian Head - June 18 (Fowler, Lafond, Derksen)
Watrous - June 25 (Hultgreen, Collins, Fowler)
Carlyle - June 27 (Fowler, Hultgreen)
Watrous - July 3 (Hultgreen, Fowler, Entz)
Porcupine Plain - July 4 (Fowler, Hultgreen)
Swift Current - July 10 (McLeod, Dyck, Campbell, Fowler)
Paddockwood - July 16 (Fowler, Johnston, Schewe)
Leipzig - July 17 (Fowler)
Yorkton - July 23 (Johnston)
Clair - July 29 (Fowler, Entz, Johnston, Gross)

Interviews

CFQC radio interview, Saskatoon, Fowler, April 25, 1986
CBC radio interview, Regina, Fowler, April 28, 1986
CKBI radio interview, Prince Albert, Fowler, July 2, 1986
Hudson Bay Journal, interview, Fowler, July 4, 1986
Prince Albert Daily Herald, interview, Fowler, July 16, 1986
CJWW radio interview, Saskatoon, Fowler, July 22, 1986
CFQC radio interview, Saskatoon, Fowler, July 24, 1986
CJWW radio interview, Saskatoon, Fowler, Aug. 11, 1986
CKRM radio interview, Regina, Fowler, Sept. 17, 1986.
CBC radio interview, Regina, Fowler, Sept. 8, 1986
CJWW radio interview, Saskatoon, Fowler, Sept. 8, 1986
CFQC radio interview, Saskatoon, Fowler, Sept. 22, 1986
CFQC TV interview, Saskatoon, Fowler, Sept. 22, 1986
CHAB radio interview, Moose Jaw, Fowler, Jan. 13, 1987
CJWW radio interview, Saskatoon, Fowler, Feb. 4, 1987
CBC radio interview, Regina, Fowler, Feb. 12, 1987

Other Television and Visual Productions

Prairie Farm Report television shorts

(a) Assessment of winterkill
(b) Weed control in winter wheat
(c) Nitrogen fertilization on winter wheat
(d) Seeding winter wheat
(e) Winter wheat in the crop rotation

The above reports were utilized by CN Railways as part of their Farm Management Advisor program.

Reports

Fowler, D.B., H.M. Austenson, G. Lafond, H.M. Entz and G.E. Hultgreen. 1986. The development of winter wheat in Saskatchewan. Report submitted to the New Crop Development Fund. April 1986. 87 pages. 200 copies distributed.

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CONCLUSION AND IMPACT

Winter wheat acreage in Saskatchewan expanded from less than 2,000 acres in 1971/72 to over 800,000 acres harvest in 1985 and 1986. This increase would not have occurred without a large extension effort. Saskatchewan farmers have had access to the latest information on a reduced tillage production system (winter wheat and rye direct seeded into standing stubble) that provides for more efficient moisture utilization, higher productivity and an opportunity to extend rotations. As an added bonus, all this comes with a system that embraces the philosophies of conservation farming.

Timing of operations and management techniques, i.e., reduced tillage, for stubbled-in winter cereal production, are radically different from those of spring crop production. On the surface, the problems arising from these differences appear to be minor. However, in reality, the production scheme for stubbled-in winter wheat presents a major change in production philosophy for most farmers. This has meant that many farmers have run into difficulties in inserting winter wheat into their rotations and a large extension challenge still remains. There have been numerous problems associated with winter wheat production the past two years. In most instances, because of the lack of familiarity with stubbled-in winter wheat production, there are many simple, inexpensive, quick management practices that could be adopted by most producers to reduce their production risks and greatly increase crop returns. For example, a difference in seeding depth of 2.5 compared to 5 cm often meant the difference between a crop and no crop following the high stress winter of 1984-85. Similar observations were made following the winter of 1985-86, only in this instance seeding at the optimum date and the use of starter phosphate fertilizer was critical to survival in many areas. In addition, properly managed winter wheat fields matured early and avoided the severe stem rust epidemic of 1986. These are examples of the importance of management practices that were demonstrated at many sites in this project. These types of visual field demonstrations have a much greater impact than any other form of information transfer.

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A COMPARISON OF ROOTING PATTERNS IN SPRING AND WINTER WHEAT

K. J. Gross, M. H. Entz and D. B. Fowler
Crop Development Centre, University of Saskatchewan,
Saskatoon, Saskatchewan

INTRODUCTION

The most severe growing season drought period in Saskatchewan usually occurs in July and early August. Most of the growth of winter wheat has already occurred by the end of July and, as a result, this period of stress is usually avoided (Fowler et al, 1986). Consequently, this factor is believed to be of primary importance in giving winter wheat its characteristic ability to outyield spring wheat (Fowler, 1983).

Many measurements of plant characteristics and responses have been taken in order to determine differences in the growth of wheat that may contribute to yield. This research has included comparisons of the root growth and water extraction of spring and winter wheat. The objective of this study was to compare the rooting patterns and soil moisture depletion patterns of spring and winter wheat grown under the environmental conditions experienced in Saskatchewan.

MATERIALS AND METHODS

Field experiments were conducted in 1986 at three locations; Outlook, Goodale, and Clair. Two varieties of winter wheat (Norstar and Norwin) were seeded in the fall of 1985 at a rate of 90 kg/ha using a small plot disc-press seeder with 22.86 cm spacings. Thirty kg/ha of phosphate was applied with the seed while rates of 0 and 90 kg/ha of ammonium nitrate were broadcast by hand in the spring of 1986. Two varieties of spring wheat (Katepwa and HY320) were seeded with the same seeder at the same rate at the end of April in 1986. Again ammonium-nitrate was applied by hand at the same rates that were used with the winter wheat.

The plots were laid out in a split-block design with five replicates, one of which was used as a root wash block. A neutron probe was used to measure soil water depletion over the growing season. The probe measured the soil water in 20 cm increments starting at 10 cm in depth and continuing to a depth of 130 cm. The amount of moisture in the top 10 cm of soil was determined gravimetrically.

A partial excavation technique called the profile wall method (Bohm, 1979) was utilized to expose the roots of both spring and winter wheat. The trench was positioned transversely to the rows in the block in order to show variation within and between the plots. The profile wall was smoothed using a flat-bottomed spade and a profile knife. Roots were then exposed by removing a soil layer approximately 1.3 cm thick from the working face of the profile. This was accomplished by spraying water on the face at 276 kPa (40 psi) using a teejet nozzle on a hand-gun hooked up to a water pump. Once the roots were exposed, pictures were taken of the roots at night in order to improve contrast between the light colored roots and the darker soil. The roots were illuminated by a light source consisting of three 400 Watt bulbs.

Slides of the profile wall were analyzed later on a screen which consisted of a 3x3 grid pattern. Using a technique modified from Tennant (1975), the following formula was employed to compare the rooting patterns of spring and winter wheat:

$$\underset{\text{(intercepts/cm grid)}}{\text{ROOT DENSITY}} = \frac{\text{(NUMBER OF INTERCEPTS)}}{\text{(grid size)(\# of grid lengths counted)}}$$

Four washes were conducted at each site based on physiological stage of development. That is.

1) first wash: winter wheat - tillering; spring wheat - 3 leaf.
2) second wash: winter wheat - anthesis; spring wheat - tiller,
3) third wash: winter wheat - harvest: spring wheat -anthesis
4) fourth wash: spring wheat - harvest.

Statistical analysis of data from the profile wall method was conducted using locations as replicates since only one trench was dug at each site at a given date. Statistical analysis of the neutron data used the four replicates at each site.

RESULTS AND DISCUSSION

Profile wall method of root measurement.

In a semi-arid environment such as Saskatchewan. water usually is the limiting factor with respect to growth and yield. Thus, the ability of a crop to produce an extensively branched, deeply penetrating root system is very important in order to make the most of the available soil moisture. Previous studies have indicated that utilization of early season moisture is important for maximum yields on the Canadian prairies (Fowler et al.

1986). In this study winter wheat rooted earlier and more prolifically in the spring than did spring wheat (see Figure 1). Winter wheat had approximately 16% more roots in the uppermost soil layer on May 30. This difference would allow the winter wheat greater access to the soil water reserves which are present at this time of year. Another point of interest is the similar numbers of roots in the 10-30 and 50-70 cm depths respectively. There are two reasons for this occurrence:

1) Studies have shown that by the time the fourth leaf on the shoot has developed, the roots may exceed 30 cm in length (Russel, 1977). Due to the early seeding of the spring wheat in this study, greater differences would probably have been observed if a root washing would have occurred earlier in the growing season.

2) Both habits were under high moisture stress during this period of growth (see Table 1). However, as winter wheat was at a later physiological stage of development, the lack of moisture affected its development more severely.

TABLE 1

COMPARISON OF PRECIPITATION AND EVAPORATION PATTERNS FOR 1986 AND THE LONG TERM AVERAGE: PARKLAND AREA

	Wynyard 1986			Yorkton 25 Year Mean		
Time Period	Evap. mm	Precip. mm	E/P	Evap. mm	Precip. mm	E/P
May 1-15	96.2	45.2	2.1	80.9	18.8	4.2
May 16-June 3	207.2	4.8	43.2	134.0	31.2	4.2
June 4-June 27	118.8	35.6	3.3	171.4	52.6	3.2
June 28-July 11	181.9	65.7	2.7	108.1	34.5	3.1
July 12-July 23	89.6	26.8	3.3	86.4	24.0	3.6
July 24-Aug. 8	100.4	19.2	5.2	110.4	11.8	9.3

Source: Environment Canada

FIGURE 1. Winter and Spring Wheat Root Growth.
May 30, 1986

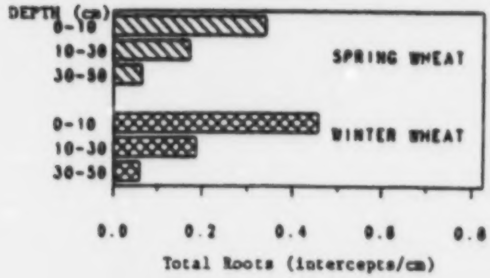


FIGURE 2. Winter and Spring Wheat Root Growth.
June 22, 1986

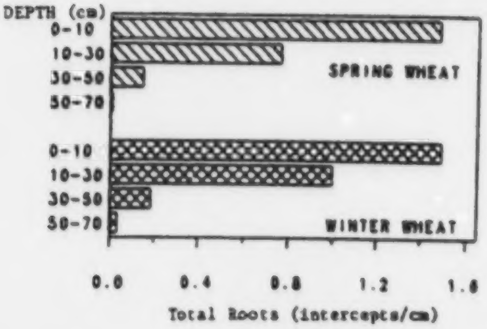
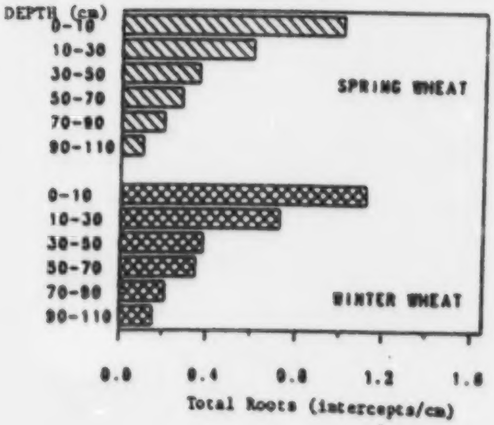


FIGURE 3. Winter and Spring Wheat Root Growth.
July 13, 1986



The next sampling period occurred when the winter wheat was at anthesis and the spring wheat was at the tillering stage. At this date (June 22 was the average time of washing between the three sites - see Figure 2) a new trench was dug and root observations were repeated. Several trends are illustrated from Figure 2:

1) There were more roots at each depth than there were at the previous date,

2) Most of the roots from both spring and winter growth habits occur in the top 30 cm of soil and this correlates well with results from other studies (Garay et al. 1983).

3) The two growth habits had rooted more deeply,

4) The advantage winter wheat held over spring wheat at this date was no longer in the first depth but occurred in the form of more roots/cm in the three lower depths.

5) The two growth habits achieve near maximum root proliferation relatively early in the growing season (Figure 4).

Figure 2 also illustrates the greater root proliferation of winter wheat at depth, most notably in the 10-30 and 50-70 cm depths respectively. This is of some importance since lower roots become more vital as the surface soil layers dry out (Welbank et al. 1973).

Finally, Figure 3 shows the number of roots in the soil profile at the various depths prior to the harvest date of winter wheat and anthesis of spring wheat. The figure indicates how similar rooting patterns of the two growth habits were by this time in the growing season. Although the rooting patterns were five year average. This resulted in a tenfold increase in stress (note the E/P values) over what normally occurs during this period. This increase in stress early in the growing season undoubtably restricted growth as a result the differences in rooting patterns between the two habits probably decreased.

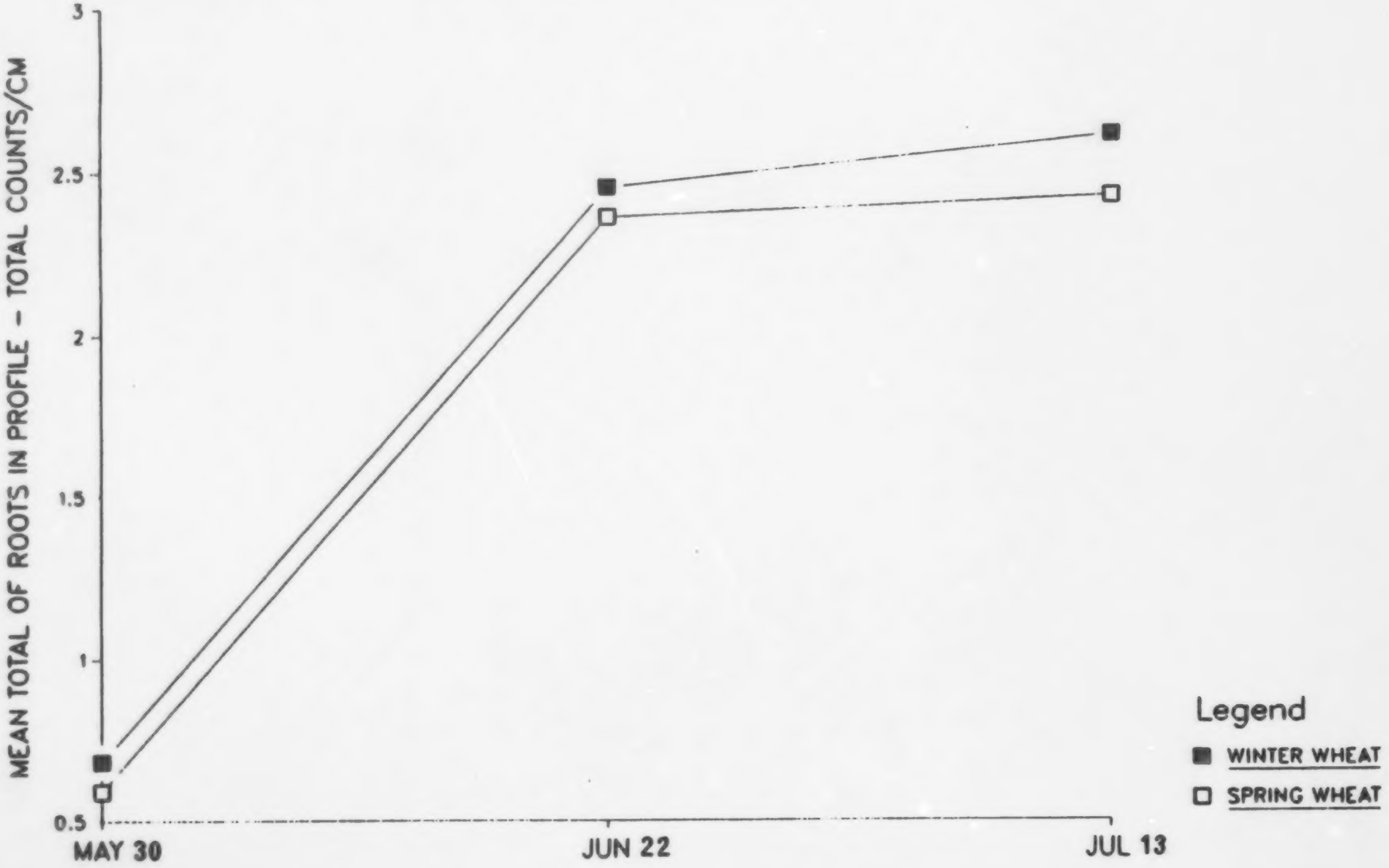
Water Extraction Technique.

The neutron probe was used to measure soil moisture content thereby giving an indication of root activity (Cholick et al, 1977). That is, the presence of roots are correlatec with soil moisture depletion. Since the amount of roots/cm of soil is important when evaluating the use of soil water by plants (Smika et al, 1982), this study used the neutron probe technique to compliment the profile wall method.

Figure 5 illustrates the amount of water (in cm of water/cm of soil) in each of the top three depths. This figure is made up from data combined from the three locations. It is interesting to note that although the soil water content of both habits is quite similar, there was a significant difference at Clair between the water use of spring and winter wheat for the first depth. The ability of the neutron probe to identify these differences is partly due to replication at each site that was not possible with the profile wall technique.

It is apparent that the water content of the surface soil (0-10 cm depth) was depleted quite early in the growing season (see Figure 6). This indicates not only an increase in evaporation from these surface layers, but also shows that the

FIGURE 4
1986 ROOT WASH STUDY
INCREASE OF ROOTS OVER THE GROWING SEASON



similar, it may be important to note that winter wheat still held a slight advantage with respect to root number at various depths.

The number of roots in the top two depths appeared to have decreased since the prior washing date. Several reasons may account for this phenomenon:

1) Roots in these layers were dying back due to lack of moisture in these zones (see Figures 5 and 6).

2) Although root systems are genetically controlled they are sensitive to the soil environment (Hurd et al, 1973). Thus, as a different sample area was studied to record these values, the variability of the soil may have played a role.

3) Roots generally begin to die back after anthesis.

These observations suggest that there are differences in the rooting patterns of the two growth habits. Field observations also supported these conclusions. However, total rooting differences were not significant when analyzed statistically. A comparison of the intercepts/cm at each depth has yet to be done. High variability of the data did not allow detection of differences between the mean number of roots totalled over depths for spring and winter wheat. This appears to be a common problem with root studies (Irvine, 1978; Cholick et al, 1977) and indicates that greater replication is required to detect differences (Schuurman, 1965). The fact that 1986 was an abnormal year with respect to precipitation (Table 1) could also have been a factor in masking differences between spring and winter wheat.

Table 1 indicates that from May 15 - June 3 the amount of precipitation that occurred was down drastically from the twenty-

FIGURE 5. Indication of Root Growth by Water Extraction. Comparing Spring and Winter Wheat. May 15, 1986

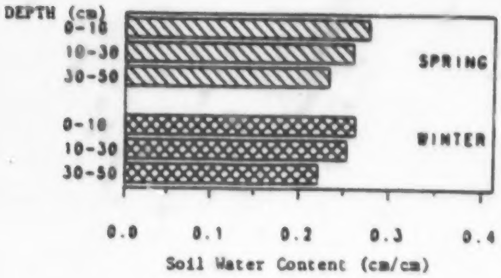


FIGURE 6. Indication of Root Growth by Water Extraction. Comparing Spring and Winter Wheat. May 30, 1986

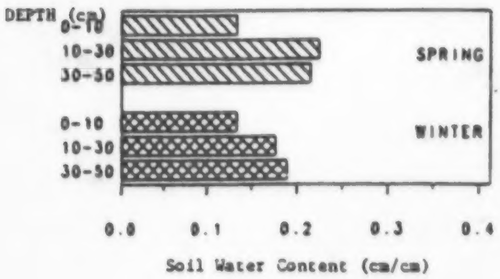
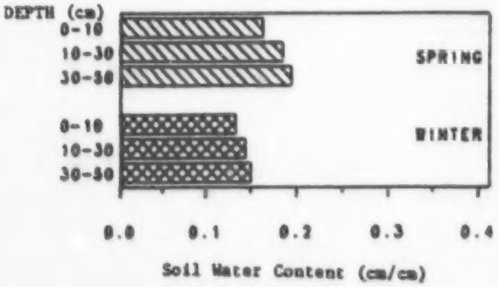


FIGURE 7. Indication of Root Growth by Water Extraction. Comparing Spring and Winter Wheat. June 20, 1986



roots have proliferated in this area and, as a result, used the available moisture.

Figure 6 also indicates greater rooting activity by winter wheat at the two lower depths as shown by the difference in soil water content when compared to spring wheat. Statistical analysis at this date showed significant differences between spring wheat and winter wheat with respect to soil water content in the second depth at all three sites. In addition, the third depth was proven to have shown differences in water content between spring and winter wheat at Outlook.

Finally, Figure 7 shows the further depletion of water in the lower depths as the growing season progressed. This coincides with the increased root growth in these zones shown by the profile wall technique. Clair and Outlook showed signifecant differences in the soil water content between the two habits in all three depths at this date. This diagram presents only the three depths for reasons of simplicity. Also, with the exception of depth four at Outlook, these three soil zones were the only depths at which significant differences were achieved. Schuurman (1959, cited in Hurd) had results similar to these even though he found roots below these soil zones. He conjectured that as long as the water supply is plentiful nearer to the surface, roots will not take moisture from below this area. However, this is not necessarily the only reason for this phenomenon as our studies indicated that there was water depletion below this zone, but the water use by the two growth habits in those zones was not significantly different.

Water-use efficiency and Yield Components.

Moisture availability during the growing season is one of the major factors limiting crop productivity on the prairies. Thus, it is important that a crop growing in such an area have the ability to make efficient use of the moisture that is available. As winter wheat establishes early, it begins to use water as much as two to three weeks before spring wheat at a time when the prevailing climate is cooler (Fowler et al, 1986). This results in the higher water-use efficiency (WUE) of winter wheat (see Table 2). It follows that the greater root distribution of winter wheat at this time of year will allow it to make more efficient use of the available water.

The relationship between grain yield and water use has been shown to be a positive one (Steppuhn et al, 1986). This positive relationship is illustrated in Table 2. The difference in yields were due mainly to significant differences in 1000 kernal weight and tiller number. There were also very significant differences in percent protein at all three sites, while Total Water Use (TWU) was signicantly different at Clair and Goodale. WUE values at Goodale and Outlook appear to be quite low, this is likely due to rainfall that occurred late in the growing season and was therefore relatively unavailable for crop use.

CONCLUSION

Earlier research has pointed out that winter wheat roots much deeper than does spring wheat (Black et al, 1981). However, due to the relatively short growing season and dryland conditions

Table 2

YIELD COMPONENTS AND WATER USE EFFICIENCY OF THE WHEAT VARIETIES

SITE	VARIETY	YIELD COMPONENTS TILLERS (#/m^2)	SEEDSPER TILLER	1000 KERN. WT.	YIELD (kg/ha)	PROTEIN (%)	PROTEIN YIELD (kg/ha)	TWU (**)	WUE (*
Clair	Spring:								
	Katepwa	365	18.96	31.8	2122	17.1	362.7	29	73.1
	HY320	353	15.90	42.3	2277	14.1	318.8	29	79
	Winter:								
	Norstar	461	19.33	31.1	2723	13.2	358.4	18	151
	Norwin	475	14.22	30.1	1994	13.5	266.3	17	116
Goodale	Spring:								
	Katepwa	176	20.65	29.3	1042	18.5	192.9	31	33.
	HY320	150	22.85	41.4	1385	16.2	222.1	31	45.4
	Winter:								
	Norstar	277	20.97	24.3	1323	14.7	195.1	24	54.6
	Norwin ***	-	-	-	-	-	-	-	
Outlook	Spring:								
	Katepwa	163	31.48	28.6	1425	16.5	233.4	29	49.
	HY320	139	31.87	33.0	1462	15.3	219.5	29	50.4
	Winter:								
	Norstar	161	42.43	27.1	1496	14.4	214.0	26	57.4
	Norwin	309	25.28	27.8	1868	13.6	252.4	29	65.5

* Water-use efficiency in kg/ha/cm

** Total water-use: May 13 - Harvest

*** Norwin was winterkilled - poor stand.

Note: Values may be rounded off to the nearest decimal.

this is not the case in Saskatchewan. This study shows that the yield advantage of winter wheat is probably due to the fact that early in the growing season it roots deeper and more extensively than does spring wheat. This enables winter wheat to use the early season stores of moisture more efficiently (Fowler, 1985).

Although the spring wheat roots as deeply as winter wheat by anthesis; by this time the soil has lost the greater part of its moisture reserves. Thus, the lower yield of spring wheat is likely at least partially due to its poor WUE in the early part of the growing season.

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INFLUENCE OF NITROGEN FERTILIZATION ON WINTER WHEAT ROOTING PATTERNS AND SOIL WATER EXTRACTION

M.H.Entz, K.J. Gross, D.B. Fowler, E. de Jong and K.J. Greer
Crop Development Centre and Saskatchewan Institute
of Pedology, Univeristy of Saskatchewan

ABSTRACT

A partial excavation technique called the profile wall method was utilized in 1985 and 1986 to investigate effects of ammonium nitrate additions on rooting patterns of Norstar winter wheat (Triticum aestivum L.). Additional nitrogen was found to increase root growth, especially at tillering. Increases in soil water extraction were measured at the same time indicating a positive relationship between root density and soil water utilization.

Placement of the fertilizer in mid-row bands at seeding time did not change crop rooting patterns compared to spring broadcast nitrogen applications. Fall fertilization was actually less effective with respect to protein yield; broadcast applied treatments generally had higher grain yields and higher protein concentration.

Roots of winter wheat grew to an average 120 cm depth. Nitrogen fertilization did not affect final root depth. Environmental factors appeared to be important in determining root depth. Soil moisture limitations were observed a t several locations in 1986.

INTRODUCTION

Modification of crop root systems by soil and management factors to increase root density and depth should be beneficial for increasing and stabilizing grain yields of dryland crops. Nitrogen fertilizer is one factor which is known to affect both root growth and utilization of soil profile water (Kmoch et al., 1957; Wilhelm et al., 1982). Bond et al. (1971) found that applied nitrogen increased vegetative growth and soil water extraction by wheat. It was also observed that in 2 of 3 years, this resulted in less water being extracted after heading. While many workers have reported increased root density and water use with added nitrogen, effects of added nitrogen on rooting depth appear much less dramatic (Kmoch et al., 1957; Wilhelm et al., 1982). Roots of winter wheat were found to grow to a 1.2 m depth in Nebraska (Wilhelm et al., 1982) and 2.0 m in Montana (Black et al., 1983).

Lupton et al. (1974) suggested that the most important factors controlling rooting depth were soil and climatic conditions. Both soil temperature and soil moisture content are known to influence root growth (de Jong & Rennie, 1967). Kmoch et al. (1957) reported little root growth by wheat when soil moisture tension fell below -15 bars. Low soil moisture conditions in Saskatchewan winter wheat fields may be a factor as winter wheat crops are normally seeded into stubble.

The optimum temperature for root growth is generally less than for above ground plant parts and as a result, it could be suggested that a 5° celsius baseline should apply for root growth. From available data it appears that temperature limitations in Saskatchewan winter wheat production should not be a factor in most years. Mean monthly soil temperatures at the 50 cm soil depth for May are 11.0^{o}C at Outlook, 8.8^{o}C at Saskatoon and 4.2^{o}C at Wynyard (1). It appears therefore, that soil temperature limitations should be limited to cool spring conditions in northern agricultural areas of the province. Any limiation to root development which could restrict rooting depth could leave the crop susceptible to late season drought stresses.

The objective of this study was to 1) investigate the influence of nitrogen fertilization on root growth and water utilization by winter wheat in different climatic areas of Saskatchewan, 2) to compare effects of fall banded and spring broadcast nitrogen applications, 3) to investigate the relationship between rooting patterns and soil water use and 4) to investigate the relationship between rooting patterns and grain yield.

MATERIALS AND METHODS

Field experiments were established using a randomized complete block design with 3-4 replicates. Two factors (rate and placement of nitrogen) were completely randomized within each block. Ammonium nitrate was applied at 0, 45 and 90 kg/ha; a 120 kg/ha rate was included at Perdue in 1985. A total of five locations were established over 1985 and 1986 and the sites differed in soil fertility, rotation, soil type and climate (Table 1). Individual plots were 2.5 m wide and 10 to 30 m. long.

Norstar winter wheat (Triticum aestivum L.) was seeded between August 30 and September 8 at a seeding rate of 75 kg/ha (90 kg/ha at Clair) using a small plot disc-press zero-tillage drill capable of mid-row banding with banding knives. Row spacing of 22.8 cm was used. Fall banded nitrogen was applied along with the seeding operation; the bands were placed 5-8 cm below the soil surface. Thirty kg/ha of phosphate was applied with the seed. Spring applications of N were made between April 20 and May 1 using a dribble broadcaster.

Soil water depletion to 130 cm was measured using a neutron probe beginning in mid-May. Surface moisture (0-10 cm) was determined gravimetrically. Total water used was calculated as change in soil moisture plus growing season precipitation.

Root investigations were conducted at tillering, heading and grain filling stages using the profile wall method (Bohm, 1979). A trench was dug in one replicate per site in a direction perpendicular to the direction of the plots. After the trench was dug, the profile wall was smoothed to obtain a vertical working face. Removal of a soil layer approximately 1.3 cm thick was done using water under pressure. After nightfall, 3, 400 watt bulbs were used to illuminate the exposed roots and 35 mm slide photographs were taken. This operation was carried out after dark so as to give maximum contrast between roots and soil. The photographs were later illuminated onto a 3 x 3 cm grid and the intersections of the roots with the lines were measured for individual soil depths (0-10; 10-30; 30-50; 50-70; 70-90; 90-110; 110-130 cm). Rooting depth was expressed as intercects/cm. The Perdue data was expressed as both intercects/cm and total root length (Tennant, 1976). Rooting depth was established in the field on the exposed wall.

At Watrous, where no direct root observations were made, rooting depth was established by soil moisture depletion patterns, a technique which has been previously used by Cholick et al. (1977).

Grain yield and yield component as well as seed protein were measured. Protein yield was calculated as grain yield (kg/ha) x % seed protein. Water use efficiency was calculated as kg grain/ha/cm total profile water use.

For the root density measurement, statistical analysis was done using locations as replicates. For crop water use and agronomic data, analyses were done on a per site basis. Each soil depth was analyzed individually, plus the total soil profile (0-130 cm) was analyzed as a whole. In addition, combined analysis using depth was also carried to investigate the influences of nitrogen on the relative distribution of roots and soil water extraction within the profile.

RESULTS AND DISCUSSION

Root development - While a final rooting depth of approximately 110 cm was achieved at all locations, the rates of rooting depth differed widely (Figure 1). At Perdue, the crop had reached its maximum depth much earlier in the growing season than at the other sites. From the information in Table (2), it is clear that soil temperature did not appear to be the limiting factor to rooting depth. For all locations root depth temperature was at least 8.5 celsius, with the lowest soil temperature recorded at Perdue. Low soil moisture content appeared to limit the rooting depth (Figure 2). Root growth between tillering and heading was found to be closely related to amounts of available soil moisture in the soil layer directly below the deepest roots.

FIGURE 1.

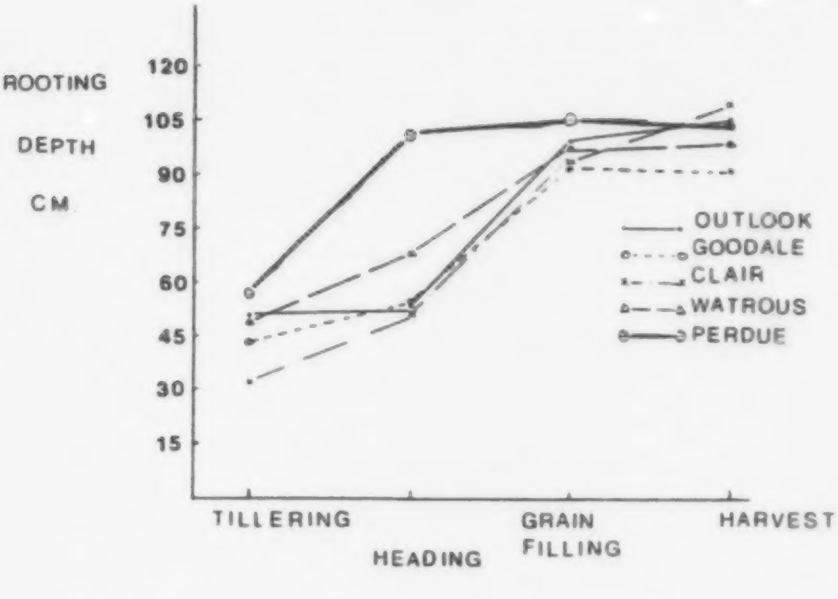


FIGURE 2.

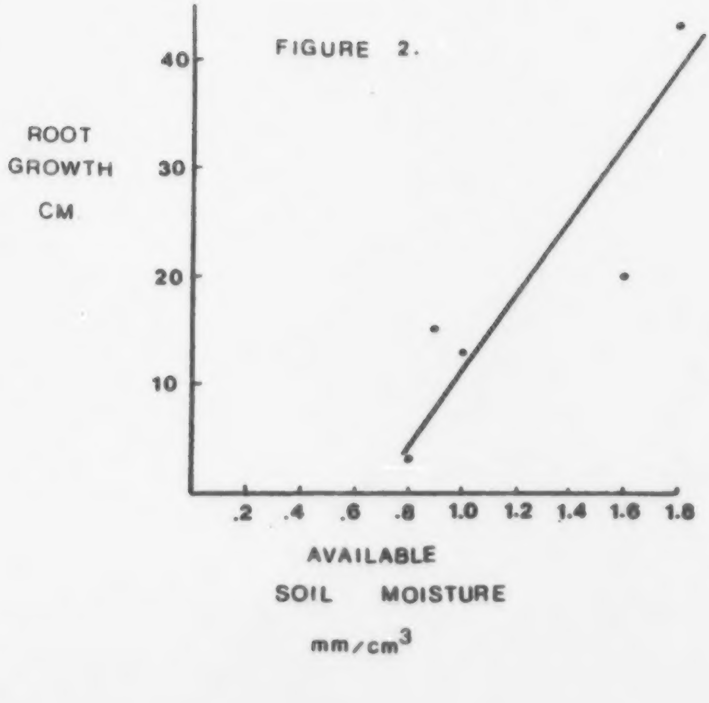


Table 1. Pertinent agronomic, soil and climatic information

Location	Soil Test NO_3-N kg/ha	Growing season precip (cm)	Previous crop	Soil association	Soil type
Outlook 1986	54	21.5	Canola	Elstow	silty loam
Goodale Farm 1986	29	21.5	Canola	Elstow	silty loam
Clair 1986	18	17.3	Barley	Yorkton	loam
Watrous 1986	51	16.2	Barley	Weyburn	clay loam
Perdue 1985	70	11.6	Chem fallow	Elstow	clay loam

TABLE 2 SOIL TEMPERATURES AT ROOTING DEPTH.

Zadok's growth stage	Location	Rooting Depth (cm)	Soil Temperature (C)	
			50 cm	100 cm
31 end of May	Outlook	49	14.7	9.1
	Goodale	43	11.3	5.3
	Clair	35	11.8	6.5
	Watrous	50	-	-
	Perdue	56	10.5	6.0
58-60 mid-June	Outlook	52		12.6
	Goodale	56		9.3
	Clair	50		9.9
	Watrous	70		-
	Perdue	99		8.5

Measurements of root density indicated that root growth generally increased from early in the growing season to grain filling (Table 3). Maximum densities for the Outlook and Goodale Farm locations were achieved at heading with a downward shift in the rooting pattern between heading and grain filling. Similar observations in cotton have been made by Klepper and co-workers (1973). They attributed their observation to death of upper roots due to desiccation and considerable proliferation at lower depths. At Clair, maximum root density was not observed until early grain filling (Table 3). This location may have had more below ground growth later in the season as the crop here was phenologically less developed by the time moisture conditions improved in late June. As a result, it made better use of this moisture than the crops at Outlook and Goodale; the difference being reflected in a higher water use efficiency at Clair (Table 6). Only data for the July 3 sampling date at Perdue is given in Table (3). By July 3, the crop at this site had achieved its maximum root density and depth .

Combined means for all locations in 1986 indicated that the distribution of roots within the profile was significantly affected by depth (Table 4) with most roots located in the upper soil profile. By mid-June, an average of 90% of the roots were located in the top 30 cm. By early to mid-July however, roots were more evenly distributed with an average of 85% of roots located in the upper 70 cm of the 110 cm root zone.

Nitrogen effects on root development - No significant effects of nitrogen or placement were observed for any of the sampling dates, even where fairly large differences in rooting patterns were observed (Table 3 and 4). Similar results have been reported by Kmoch et al. (1957) who found that this type of work often lacks the precision to detect significant differences between treatments. Lack of significance in our case was likely due to the limited sample and replicate numbers. Also, yields in 1986 were generally low (below the 2800 kg/ha average) and crop responses to nitrogen were small.

Despite the lack of significance, it appeared that next to environmental conditions, the greatest effect on root growth was nitrogen rate. This was especially clear from the 1985 results at Perdue (Figure 3). For the combined 1986 sites, any influence of nitrogen was limited to the tillering period with little effect at later growth stages (Figure 4).

Placement of nitrogen had no apparent effect on root density. Firstly, root photographs indicated no evidence of localization of roots around the banded area. Root densities in the 0-10 cm depth were very similar for both placement methods (Table 4). These observations indicated that the fertilizer nitrogen had likely been moved away from the placement area. Such movement could be expected as significant amounts of water would have moved through this area between early September and mid-May. Also, soil temperatures by the middle of May were high enough to have allowed nitrification of any bound NH_4^+. Generally, band placement resulted in fewer roots; the most striking observation of this was at Perdue in 1985 (Figure 5).

Soil Water Extraction

Crop water use was measured at regular intervals during the growing season beginning in mid-May. The data reported here will begin with water

Table 3. Root density of Norstar winter wheat for 1985 and 1986

Crop growth stage	Depth (cm)	Root intersects/cm Outlook 1986	Goodale 1986	Clair 1986	Perdue 1985
Tillering	0-10	.22	.65	.46	-
	10-30	.27	.29	.09	
	30-50	.03	.11	0	
		.52	1.05	.55	
Heading	0-10	2.01	1.00	1.54	-
	10-30	1.02	.66	.87	
	30-50	.53	.21	.11	
	50-70	.01	.02	.06	
		3.57	1.89	2.58	
Grain filling	0-10	1.31	.33	1.48	.37
	10-30	.38	.39	1.13	.53
	30-50	.17	.23	.54	.49
	50-70	.17	.20	.46	.55
	70-90	.11	.02	.24	.35
	90-110	.01	.01	.01	.05
		2.15	1.18	3.86	2.34

Table 4. Root density of Norstar winter wheat for the 1986 combined sites (root intersects/cm)

Crop growth stage	Depth (cm)	Additional nitrogen (kg/ha) 0 +BC	 +BD	 45 BC	 BD	 90 BC	 BD
Tillering	0-10	.40.	-	.37	.45	.51	.38
	10-30	.14		.20	.23	.38	.13
	30-50	.04	-	.02	.01	.20	.05
		.59		.61	.69	1.09	.57
	depth*	N*D - N.S.	P*D - N.S.				
Heading	0-10	1.37	-	1.59	1.58	1.57	1.40
	10-30	.90		.87	.75	.87	.87
	30-50	.25		.24	.15	.12	.188
	50-70	.02		.03	0	.05	.03
		2.55		2.75	2.48	2.58	2.49
	depth**	N*D - N.S.	P*D - N.S.				
Grain filling	0-10	1.04	-	1.01	.96	1.17	1.05
	10-30	.57		.76	.65	.78	.44
	30-50	.34		.40	.43	.27	.16
	50-70	.33	-	.43	.27	.23	.12
	70-90	.01		.19	.14	.10	.10
	90-110	.01		.14	.01	.01	.01
		2.31		2.95	2.49	2.57	1.90
	depth **	N*D - *	P*D - N.S.				

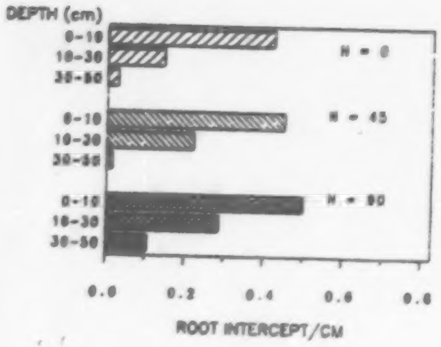
*,** - Statistically significant at the 5% and 1% level, respectively.

[1] N*D - nitrogen by depth interaction

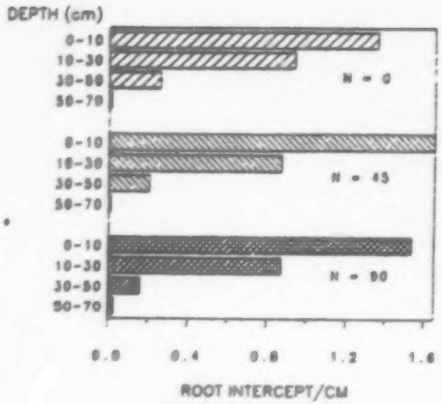
[2] P*D - placement by depth interaction

+BC - broadcast fertilizer application

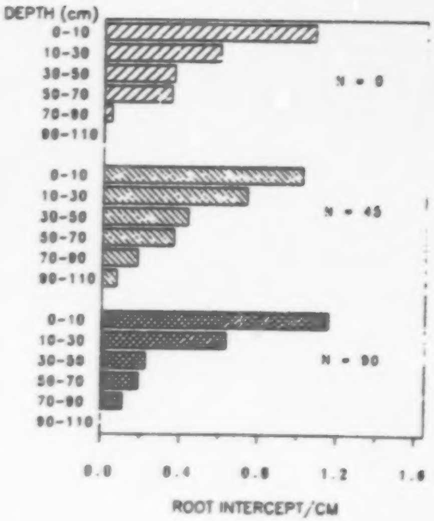
+BD - band fertilizer application



ROOT DENSITY AS A FUNCTION OF DEPTH AND NITROGEN RATE (kg/ha), AT TILLERING, 1986



ROOT DENSITY AS A FUNCTION OF DEPTH AND NITROGEN RATE (kg/ha), AT HEADING, 1986



ROOT DENSITY AS A FUNCTION OF DEPTH AND NITROGEN RATE (kg/ha), AT GRAIN FILLING, 1986

FIGURE 4

use for the early part of the growing season; between mid-May and May 30-June 3 (Table 5). The interaction between placement and depth (P*D) and nitrogen rate and depth (N*D) are given. The influence of rate alone was found to be significant at Perdue only. Nitrogen by depth interactions were significant at all other locations, and in all of these cases represented increased water use at lower depths when nitrogen was added. Placement by depth interactions were never significant indicating that placement of the nitrogen did not influence the location within the profile from which water was extracted.

Water use between mid-May, anthesis and harvest are shown in Table (6). Only at Perdue was total growing season water use affected (P = .0529). No significant effects were observed for total profile water for any other locations or at any other dates. At Outlook and Goodale, total water use was less where nitrogen was applied; an observation indicating drought stress (Olson et al., 1964).

Highlights of the analyses indicate that most significant effects occurred between mid-May and anthesis (Table 7). Few effects were observed between anthesis and harvest. Briefly, the effects at the individual locations were as follows: At Outlook, additions of nitrogen increased early season water use (significant for the 10-30 cm depth). A similar effect was found at Goodale, plus more water was used at depth by banded treatments. At Clair, additional nitrogen increased early season water use ($p<.05$ for the 10-30 cm depth) and resulted in more water used at depth. Addition nitrogen resulted in the same early season effect at Watrous. The N*P interaction for Watrous showed an inconclusive trend. At Perdue the major point of interest was the higher amount of water used between anthesis and harvest for broadcast treatments (Table 6).

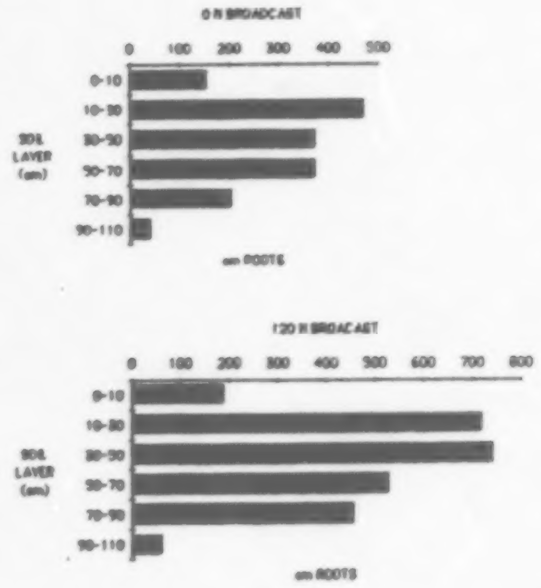


FIGURE 3.

PERDUE, SASK. 1985

Table 5. Influence of added nitrogen on crop water use from mid-May to May 30-June 1

Location	Soil depth (cm)	Applied nitrogen kg/ha						Rate effect
		0		45		90		
		[1]BC	[2]BD	BC	BC	BC	BD	
Outlook	0-10	.90	-	.90	.90	.90	.90	
	10-30	1.36		1.30	1.25	1.50	1.67	
	30-50	.73		.71	.65	.39	.43	
		2.99		2.91	2.80	2.79	3.00	N.S.
	P*D	N.S.						
	N*D	**						
Goodale Farm	0-10	1.68		1.65	1.57	1.70	1.72	
	10-30	1.34		1.12	1.19	1.28	1.42	
	30-50	.28		0	0	0	0	
		3.3		2.77	2.76	2.98	3.14	N.S.
	P*D	N.S.						
	N*D	*						
Clair	0-10	1.42	-	1.42	1.42	1.42	1.42	
	10-30	1.18		1.14	1.32	1.77	1.38	
	30-50	.42		.54	.41	.80	.39	
		3.12		3.10	3.15	3.99	3.19	N.S.
	P*D	N.S.						
	N*D	**						
Watrous	0-10	2.03		2.03	2.03	2.03	2.03	
	10-30	1.41		1.60	1.99	1.47	1.49	
	30-50	.20		.30	.93	.48	.38	
		3.64		3.93	4.95	3.98	3.90	N.S.
	P*D	N.S.						
	N*D	*						
Perdue	0-10	1.02	1.02	1.53	1.32	1.30	1.21*	
	10-30	1.34	.21	1.70	1.32	1.60	1.85	
	30-50	1.15	.74	1.19	.55	1.25	1.39	
	50-70	.46	0	.68	.30	.52	.35	*
		3.47	1.97	5.10	3.49	4.67	4.80	N.S.
	P*D	N.S.						
	N*D	N.S.						

[1] BC - broadcast fertilizer application
[2] BD - banded fertilizer application

In summary, fertilizer effects on crop water use patterns were confined mainly to the period before anthesis and to the upper 50 cm of the soil profile. Nitrogen effects in the latter half of the growing season were confined to the lower regions of the soil profile where additional fertilizer resulted in slightly more water being used.

Grain yield, protein and protein yield - Yields of grain generally increased with additional nitrogen rates however the response was significant for the Perdue site only (Table 8). No significant effects of placement were measured. Poor responses in 1986 were likely due to the very high moisture stress measured during the critical tillering to anthesis growth stages of that year (Gross et al., 1987). There were however significant effects of nitrogen on protein concentration (Table 9) and protein yield (Table 10). As protein yield is a combination of grain yield and percent protein, it will be used here to compare nitrogen effects. Since grain yield and protein concentration were generally lower for banded treatments, it stands to reason that protein yield should be less as well. Over all 5 sites protein yields were an average of 13.8% lower for banded treatments (Table 11). Therefore, band placement in early September was not as efficient as broadcast at the end of April. It should be noted that fall banding in winter wheat production is done at seeding (early September). Losses or at least reduced efficiency of the additional nitrogen could be expected. The 13.8% lower response to added nitrogen when banded, support the provincial guidelines which state 10% less efficiency with fall banding compared with spring broadcast applications (2).

Table 6. Influence of added nitrogen on crop water use and water use efficiency

Location	Nitrogen rate kg/ha	cm water use May 15 to anthesis [1]BC	[2]BD	cm water use anthesis to harvest BC	BD	cm water use May 15 to harvest BC	BD	Water use efficiency kg/ha gain/cm water BC	BD
Outlook	0	12.75	-	10.36	-	23.11	-	70.2	-
	45	12.18	12.63	10.22	11.21	22.40	23.84	65.5	51.9
	90	12.24	12.46	9.30	9.97	21.54	22.43	85.0	97.1
Goodale Farm	0	16.44	-	8.11	-	22.60	-	60.5	-
	45	14.74	16.75	7.55	9.59	20.33	24.39	69.0	61.4
	90	16.12	16.48	6.82	7.85	20.99	22.37	68.0	68.1
Clair	0	10.68	-	9.58	-	20.26	-	100.2	-
	45	9.68	10.33	10.68	9.97	20.36	20.31	110.8	102.1
	90	11.53	9.76	9.20	10.27	20.73	20.04	114.9	101.2
Watrous	0	10.41	-	6.61	-	17.01	-	61.6	-
	45	12.95	11.49	5.48	5.36	18.43	16.84	76.9	68.0
	90	12.12	12.77	6.31	6.28	18.43	19.05	94.8	61.6
Perdue	0	5.36	4.49	20.77	21.11	26.13	25.61	127.2	140.9
	45	6.68	5.70	20.31	19.50	27.00	25.28	167.2	168.9
	90	6.68	6.40	20.05	20.05	26.74	26.46	158.0	156.5
						p= (.0526)			

[1]BC - broadcast fertilizer application.
[2]BD - band fertilizer application.

Table 7. Highlights of the analyses of variance for crop water use by depth

Location	Interaction	mid-May to anthesis	Anthesis to harvest	mid-May to harvest
Outlook	N*Depth	*	NS	*
	P*Depth	NS	NS	NS
	N*P	NS	NS	NS
Goodale Farm	N*Depth	**	NS	**
	P*Depth	NS	NS	NS
	N*P	NS	NS	**
Clair	N*Depth	**	NS	**
	P*Depth	NS	NS	NS
	N*P	NS	NS	NS
Watrous	N*Depth	*	NS	**
	P*Depth	NS	NS	NS
	N*P	NS	NS	**
Perdue	N*Depth	NS	NS	NS
	P*Depth	NS	*	NS
	N*P	NS	NS	NS

*,**Statistically significant at the 5 and 1% level, respectively.

DISCUSSION

Relationship between roots and soil water extraction - A relationship between rooting depth and depth of soil water extraction can be observed from the data shown in Figure (6). For both the June 16 and harvest dates, the zone of soil water extraction coincided with the bottom of the rooting zone.

With respect to the relationship between root density and soil water extraction, we know that additions of nitrogen increased the rate of root growth (Figure 3) and soil water depletion (Table 5). Thereby, we can infer that the increased soil water use was caused by the presence of more roots feeding in the soil profile. While this inference is likely quite realistic, another factor which could have influenced the rate of soil water depletion was the amount of above ground growth. Although it has not been discussed here, it is known that additional top growth provides the "sink" for soil water as well as a larger transpiration stream. Whatever the reason, it is clear that the relationship between root density and soil water use is real. It could be suggested that this relation would hold until soil water reserves become depleted; a common phenomena in dryland agriculture.

Relationship between roots and grain yield - Since no direct comparisons between these two plant parts were made, a direct relationship is difficult to establish. However, it was observed that grain yield generally increased with increased root density. This is especially true when comparing the root densities and grain yields at Goodale and Clair. Higher grains yields at Clair coincided with higher root densities. Rooting depth at heading may also have been a factor. Perdue had a much deeper root system at the heading stage and also produced a much higher

Table 8. Influence of Additional Nitrogen on Grain Yield of Norstar Winter Wheat

Location	Nitrogen rate kg/ha	Grain Yield kg/ha Placement method BC	 BD
Outlook	mean	1641	1680
Goodale Farm	mean	1400	1464
Clair	mean	2223	2045
Watrous	mean	1405	1123
Perdue	0	3324	3609
	45	4528	4271
	90	4227	4143
		*	*

BC - broadcast fertilizer application
BD - banded fertilizer application

*,** - statistically significant at the 5% and 1% level, respectively.

Table 9. Influence of Additional Nitrogen on Seed Protein Concentration

Location	Nitrogen rate kg/ha	Percent Protein Placement method BC	 BD
Outlook	0	12.0	12.0
	45	14.0	13.1
	90	14.4	13.2
		*	*
Goodale Farm	0	10.5	10.8
	45	12.5	12.3
	90	13.5	12.9
		*	*
Clair	0	10.7	11.8
	45	13.0	12.9
	90	13.7	13.2
		*	*
Watrous	0	10.8	11.1
	45	12.9	13.7
	90	14.1	13.6
		*	*
Perdue	0	10.1	10.2
	45	11.4	10.9
	90	12.2	11.8
		*	*

BC - broadcast fertilizer application
BD - banded fertilizer application

*,** - statistically significant at the 5% and 1% level respectively

Table 10. Influence of Additional Nitrogen on Protein Yield

Location	Nitrogen rate kg/ha	Protein Yield kg/ha Placement method BC	 BD
Outlook	0	195.2	194.8
	45	209.5	162.0
	90	261.1	287.2
		NS	NS
Goodale Farm	0	148.5	152.5
	45	181.2	198.1
	90	211.2	207.0
		NS	NS
Clair	0	216.8	242.0
	45	264.3	244.9
	90	269.1	268.1
		*	*
Watrous	0	111.6	111.6
	45	178.2	141.7
	90	235.4	150.7
		*	*
Perdue	0	335.7	368.1
	45	516.1	465.5
	90	515.6	488.8
		*	*

Protein Yield = Grain Yield * Percent Protein
BC - broadcast fertilizer application
BD - banded fertilizer application
*,** - statistically significant at the 5% and 1% level, respectively.
NS - non-significant

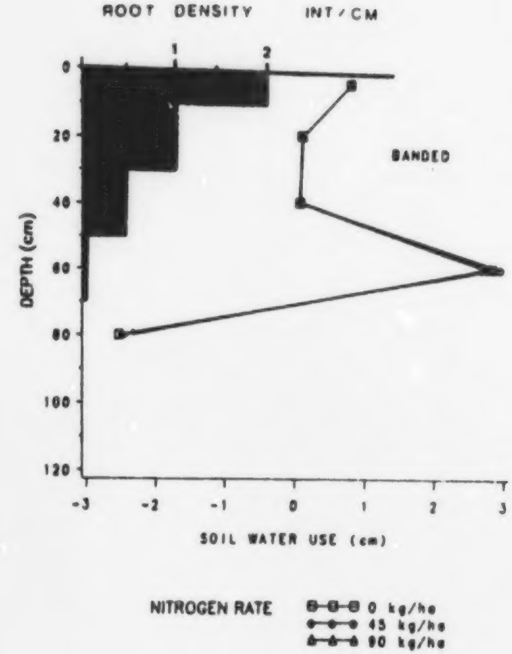
Table 11. Comparison between Fall Broadcast and Spring Banded Treatments

Location	Nitrogen rate kg/ha	Increase in protein yield: broadcast over banded placement (%)
Outlook	0	
	45	29.3
	90	9.0
Goodale Farm	0	
	45	-8.5
	90	2.0
Clair	0	
	45	7.9
	90	0.0
Watrous	0	
	45	25.7
	90	56.2
Perdue	0	
	45	10.8
	90	5.4
	Overall Mean	13.8 %

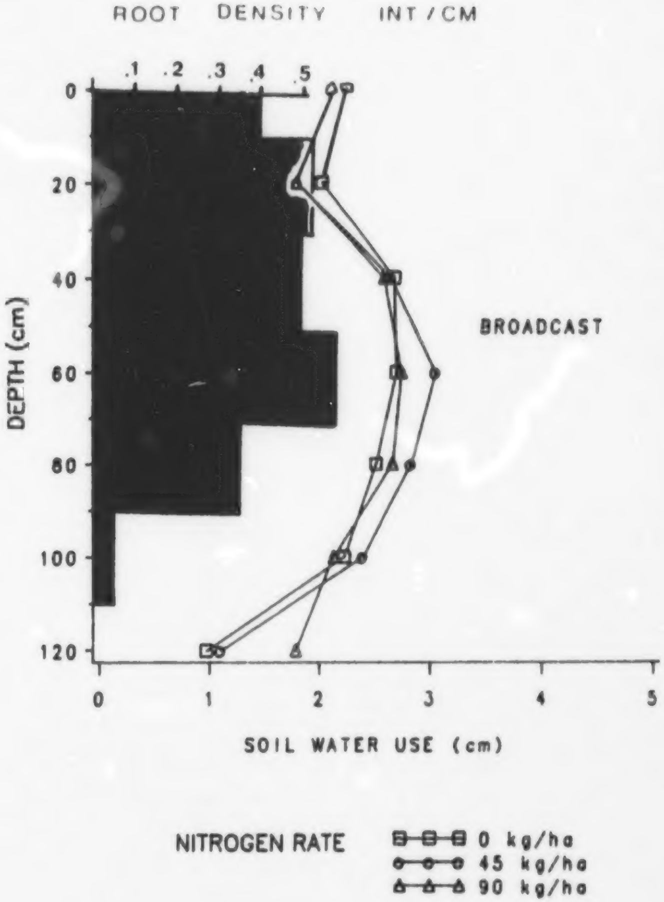
grain yield compared to the other sites.

The role of nitrogen - Additional nitrogen clearly affected the below ground plant parts by increasing the vegetative growth of roots. Higher levels of root density in the soil resulted in more water being extracted especially during the first half of the growing season. The effect of increasing soil water extraction between tillering and anthesis appears to be a positive one as this period is most sensitive to water deficits. This may be why grain yields have been shown to be relatively stable, even where nitrogen fertilization has resulted in less available water in the latter half of the growing season (Viets, 1962). Another reason for this could be that additional nitrogen can result in better exploration of deep water reserves. Under conditions of abundant water, the ability of fertilized crops to utilize more of the available water (Olson et al., 1964) becomes an important factor to achieving higher yields. The relationship of nitrogen response and different moisture environments for winter wheat in Saskatchewan has been shown by Fowler et al. (1987).

Environmental effects - Roots clearly require an environment favourable for their growth if they are to achieve maximum depth and maximum density. It appears that soil moisture (and possibly soil temperature) is the most important factors determining root growth of winter wheat (and probably all other crops) in Saskatchewan. Crop root systems appear as susceptible to stress conditions as above ground plant parts.



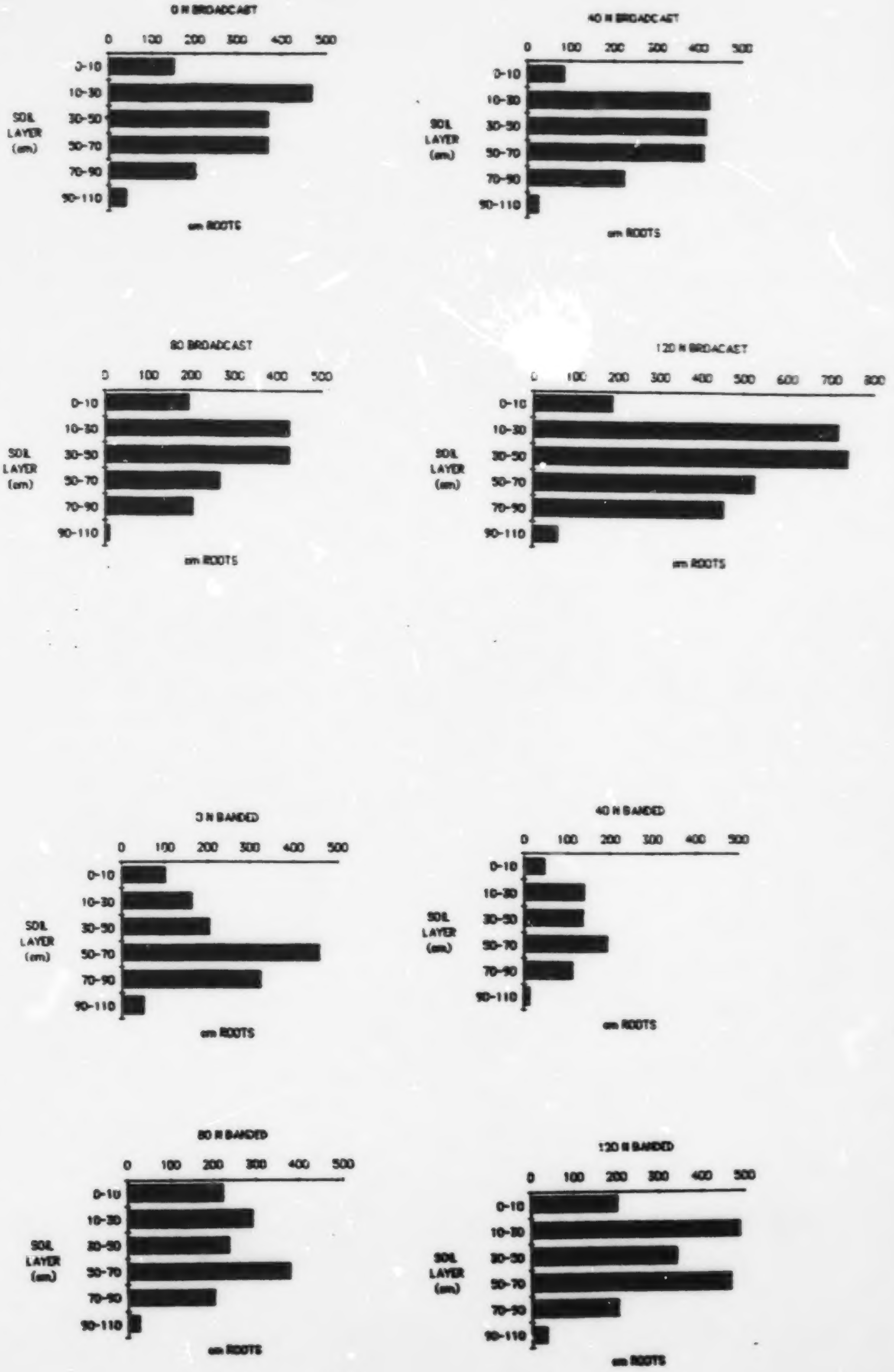
SOIL WATER USE BETWEEN MAY 13 AND JUNE 16
OUTLOOK, SASKATCHEWAN, 1986



SOIL WATER USE BETWEEN MAY 17 AND AUGUST 15
PERDUE, SASKATCHEWAN, 1985

FIGURE 5

Figure 6. Perdue 1985



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COLD HARDINESS OF FORAGE GRASSES GROWN ON THE CANADIAN PRAIRIES

A.E. Limin and D.B. Fowler
Crop Development Centre, University of Saskatchewan
Saskatoon, Saskatchewan, Canada S7N 0W0

SUMMARY

Cold hardiness ratings of 18 forage grass species, and cold hardy reference cultivars of winter wheat (Norstar) and rye (Puma), were compared to provide estimates of the winterkill risk for forage grasses established in the spring and fall on the Canadian prairies. The least cold hardy forage species, orchard grass and reed canary grass, were considerably less cold hardy than Norstar winter wheat when fall sown. Consequently, fall seeding of these species should not be recommended in this region because of the high risk of winterkill. Cultivars of many other species approximated the cold hardiness of Norstar and would require snowcover protection to ensure good winter survival if fall sown. None of the forage cultivars evaluated in the seedling stage were more cold hardy than Puma winter rye. Plants from forage grass stands established in the spring averaged 4.7 ^{o}C hardier than comparable seedlings from fall plantings. This resulted in established forage grass stands that ranged from cold hardiness levels similar to Norstar to superior to Puma. These greatly improved cold hardiness levels reduce the importance of snowcover protection for the overwintering of established stands of many forage species.

KEY WORDS: Forage grasses, cold hardiness, seeding date, winter survival.

SHORT TITLE: Cold hardiness in forage grasses.

INTRODUCTION

The severe winters experienced on the Canadian prairies subject winter annual and perennial grass stands to high levels of cold stress. A species ability to survive the harsh winters of this region is influenced by both genetic and developmental factors (White and Horner 1943; Andrews et al. 1960; Fowler and Gusta 1977; White and Currie 1980). These factors have been studied in detail for winter cereals produced in western Canada (Fowler et al. 1983). In contrast, only a few investigations into cold hardiness of forage grasses have been reported. Results of a national survey of the winter hardiness and survival of forage crops have been reported by Ouellet (1976). This survey demonstrated differences in winter survival of a number of forage species and cultivars within regions across Canada. LT_{50} values have been determined for several turf (Gusta et al. 1980) and forage grasses (Gudleifsson et al. 1986), however, these ratings were not related to forage production in western Canada. The present study was initiated to obtain objective cold hardiness ratings that could be utilized to estimate the winterkill risk for 18 forage grass species when established in the spring and fall on the Canadian prairies.

MATERIALS AND METHODS

A total of 35 western Canadian forage grass cultivars and lines were evaluated for cold hardiness (Table 1). Seed of Russian wild ryegrass and 'Clarke' intermediate wheatgrass was supplied by Dr. T. Lawrence, Agriculture Canada Research Station, Swift Current, Saskatchewan. The seed of the remaining cultivars was provided by Dr. R.P. Knowles, Agriculture Canada Research Station, Saskatoon, Saskatchewan. Cold hardy reference cultivars of winter wheat (Norstar) and rye (Puma) were included in the freeze tests for purposes of comparison.

Trials were sown with a small plot hoe-press drill in the middle of May and the last week of August in 1983 and 1984 at Saskatoon, Saskatchewan. Experimental design was a two replicate split plot with seeding dates as the main plots and cultivars as the sub-plots. Plants from each plot were removed from the field for cold hardiness evaluation in the last week of October.

The freeze test procedure was similar to that described by Fowler and Carles (1979). Crowns were prepared for freezing by removing the roots and leaves of each plant. Plant crowns were covered in moist sand and placed in a programmable freezer which cooled at 2 °C/h down to -17 °C and then at 8 °C/h. Five crowns of each replicate were removed at 2 °C intervals over the selected temperature range for each entry. Plant crowns were allowed to thaw slowly and then transplanted into a soil-sand-peat (1:1:1) mixture and maintained at approximately 18 °C for four weeks. The cold hardiness of the crown was expressed as an LT_{50} (temperature at which 50% of the population for each entry failed to regenerate roots and shoots).

RESULTS AND DISCUSSION

The cold hardiness requirements for overwintering of cereals on the Canadian prairies have been studied in detail (Fowler 1983). These studies have identified low temperature as the primary stress limiting winter survival (Fowler et al. 1981, Fowler et al. 1983). A close linear relationship between LT_{50} of fully acclimated plants and winter survival has also been established (Fowler et al. 1981). Properly managed, hardy winter rye cultivars, such as Puma, can usually be overwintered in this region without the protective insulation provided by snowcover, e.g., on summerfallow. The winter wheat gene pool does not provide the cold hardiness potential found for rye (Fowler et al. 1983). Consequently, outside of the chinook region in the southwest, hardy winter wheat cultivars, such as Norstar, can be consistently overwintered only when protected by a minimum of 10 cm of unpacked snow (Fowler and Gusta 1978). The importance of snowtrapping in the overwintering of grasses has also been demonstrated by White and Horner (1943). In the present study, these relationships have been utilized to estimate the winterkill risk for forage grasses established in the spring and fall on the Canadian prairies.

Considerable variability in LT_{50} was found for the perennial forage grass species considered (Table 1). When sown in the fall, at the optimum seeding date for winter wheat and rye (Fowler 1982), cultivars of reed canary grass, orchard grass, altai wild ryegrass, meadow bromegrass and northern wheatgrass entered the winter significantly ($P \leq .05$) less hardy than Norstar winter wheat. Therefore, at this growth stage, the risk of winterkill for these species would be considered high unless they were protected by a deep snowcover. Seedlings of many of the remaining species demonstrated a level of cold hardiness comparable to winter wheat suggesting that similar snowcover requirements are necessary to provide an acceptable winterkill risk. LT_{50} ratings of Summit crested wheatgrass seedlings were not significantly ($P > .05$) different from Puma rye indicating that cultivars of this species should provide acceptable winterkill risks even with minimal snowcover. Based on their excellent cold hardiness in established stands, it is probable that seedlings of hard fescue, Kentucky bluegrass and creeping bentgrass would be in a hardiness class similar to the crested wheatgrasses.

In winter cereals, deviations of more than two weeks from the optimum seeding date can result in a considerable reduction in winter hardiness (Fowler 1982). This reduction has been attributed to differences in the stage of growth of the plant when it enters the winter (Andrews _et_ _al_. 1960; Roberts and Grant 1968; Gusta and Fowler 1979). White and Currie (1980) observed that winter damage in forages is inversely related to the number of seedling leaves indicating that there is also a relationship between cold hardiness level and growth stage in perennial grasses. In the present study, a significant ($P \leq .01$) 4.7 ^{o}C improvement in the average LT_{50} of established forage grass plants compared to seedlings (Table 1) suggests that the relationship between growth stage and cold hardiness differs for perennial and annual grasses. In addition, significant ($P \leq .05$) cultivar by seeding date interactions indicates that the relationship between growth stage and cold hardiness expression differs among perennial grasses. In general, established plants of even the least hardy forage species developed cold hardiness levels that would put them in the same winterkill risk class as Norstar winter wheat (Table 1). Most other cultivars achieved cold hardiness levels similar to Puma winter rye. This makes them good winter risks even on open fields without provision for snowtrapping. The most cold hardy forage grasses in established stands were S-7317 crested wheatgrass, S-1792 hard fescue, Dormie Kentucky bluegrass and S-4979 creeping bentgrass. Winter damage due to cold stress is unlikely in established stands of most of these grasses.

The degree of cold hardiness observed in the established forage grasses (Table 1) indicates that winter survival has been an important factor in their selection for western Canadian conditions. Once established, only the least hardy forages are in danger of winterkill due to low temperature stress alone. In contrast, the risk of winterkill due to low temperature stress is quite high for many early fall sown forage cultivars unless adequate snowcover is assured. Present production guidelines recommend early fall, late October and spring seeding of forage grasses (Anonymous 1986). However, the observations made in this study suggest that seeding date guidelines should place greater emphasis on the cold hardiness potential of each forage cultivar and the importance of management factors designed to minimize winter stress, e.g., snowtrapping.

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Table 1. Late fall (last week of October) cold hardiness ratings (LT_{50}) of forage grass cultivars and line sown in the middle of May (established) and the last week of August (seedling) at Saskatoon, Saskatchewan. Reference winter wheat and rye cultivars were only included in the August seeding.

Species	Common name	Cultivar or line	Seedling LT_{50}	Established LT
Phalaris arundinacea L.	reed canarygrass	Frontier	-19	-23
		Castor	-17	-22
		Vantage		-24
Dactylis glomerata L.	orchard grass	Kay	-18	-23
Leymus angustus (Trin.) Pilger	altai wild ryegrass	Prairieland	-20	-28
Bromus biebersteinii Roemer & Schultes	meadow bromegrass	Regar	-19	-23
		S-7414	-22	-22
Elymus lanceolatus (Scribn. & Smith) Gould	northern wheatgrass	S-8895	-21	-30
Bromus inermis Leyss.	smooth bromegrass	Carlton	-22	-28
		Magna	-23	-28
		Baylor	-22	-28
		Beacon	-22	-28
Psathyrostachys juncea (Fisch.) Nevski	Russian wild ryegrass	Swift	-23	-31
		Cabree	-22	-30
		Sawki	-21	-28
		Mayak	-23	-29
Festuca rubra L.	creeping red fescue		-22	-30
Thinopyrum ponticum (Podp.) Barkworth & Dewey	tall wheatgrass	Orbit	-23	-27
Thinopyrum intermedium (Host) Barkworth & Dewey	intermediate wheatgrass	Chief	-24	-24
		Clarke	-24	-27
		Greenleaf	-23	
Phleum pratense L.	timothy	Climax	-25	-28
		Champ	-26	-27
		Basho	-25	-28
Elymus trachycaulus (Link.) Gould ex Shinners	slender wheatgrass	Revenue	-25	-30

'*ascopyrum smithii* Rydb. Love	western wheatgrass	S-8580		-31
lymus lanceolatus (Scribner & J.G. Smith) Gould	streambank wheatgrass			-32
gropyron cristatum (L.) Gaertner	crested wheatgrass	Nordan	-27	-30
		Summit	-30	-29
		Parkway	-28	-30
		Fairway	-28	-32
		S-7317	-28	-35
estuca ovina L.	hard fescue	S-1792		-33
'*oa pratensis* L.	Kentucky bluegrass	Dormie		-37
grostis palustris Huds.	creeping bentgrass	S-4979		<-39
riticum aestivum L.	winter wheat	Norstar	-24	
ecale cereale L.	winter rye	Puma	-31	
LSD 0.05			2.2	3.0

LT$_{50}$ was not as discrete for established plants as for seedlings, i.e., within cultivars the range between complete survival and complete kill was greater for established plants.

B. CROP DEVELOPMENT CENTRE WINTER WHEAT BREEDING PROGRAM 1986-87

ABSTRACT

The winter wheat breeding program has continued a cooperative screening project with several U.S.A. breeders. The Montana State semi-dwarf winter wheat "Norwin" was registered for commercial production in Canada through the CDC program in 1986. Unfortunately, although lines from the CDC breeding program were seeded at eleven locations throughout Saskatchewan in 1986, one of our worst rust years in 30, good agronomic practices resulted in early maturity and rust avoidance. Consequently, no information was obtained on the rust tolerance of CDC breeding material. In the fall of 1986, CDC produced semi-dwarf lines, with winter hardiness similar to Norstar and good yield potential, were planted for further evaluation at several locations in Saskatchewan.

BACKGROUND AND OBJECTIVES

Production of Winter Hardy Wheat Cultivars

Improved winter hardiness is required to reduce the risk of winterkill in winter wheat produced in Saskatchewan. This is especially important if winter wheat is to be produced utilizing traditional production methods, i.e., seeded into tilled seedbeds. Consequently, when the winter wheat program was first established, one of its objectives was the production of winter wheat cultivars with superior cold hardiness. Introductions from around the world have been screened for winter hardiness under Saskatchewan conditions and the hardiest among these have been utilized as parents in a hybridization program to produce and identify superior genotypes. Progeny of these crosses have been grown on unprotected summerfallow fields, along with Norstar checks, for the past several winters. The winter of 1980-81 provided an excellent winter survival screen for this material. However, until the winter of 1984-85, the level of winter stress was not sufficient to permit further selection in these populations. In the fall of 1984 six replicates of five hundred F_6 lines were seeded on unprotected summerfallow at two locations in the Saskatoon area. If nothing else, the winter of 1984-85 provided an excellent screen for winter hardiness in these populations. A number of very hardy lines were identified. However, these lines did not display cold tolerance levels that were greater than the hardy parents. Single plant selections from these populations were grown in the greenhouse for seed increase during the winter of 1985-86. Row selections with winter survival ratings equal to or better than Norstar were evaluated in summerfallow trials which were seeded at Swift Current (776 plots) and Saskatoon (744 plots) in the fall of 1985.

Production of Agronomically Superior Semi-dwarf and Normal Height Winter Wheat Cultivars

Snow management, through practices such as stubbling-in, has reduced the winter hardiness requirement for winter wheat. All hardy winter wheat cultivars grow exceptionally tall (120 cm) under favorable growing conditions. Even though cultivars such as Norstar have excellent lodging resistance, this excessive growth is a concern under intensive management systems. Therefore, one of the objectives of the breeding program is to produce semi-dwarf cultivars with high yield potential, acceptable quality and winter hardiness equal to Norstar. Straw length is not a problem in drier regions of the province. Therefore, a second objective of the breeding program is to produce agronomically superior normal height cultivars with acceptable quality and winter hardiness equal to Norstar.

In the fall of 1984, two thousand five hundred F_3 and F_4 single lines, from semi-dwarf by hardy parents, were grown at Outlook (irrigation), Saskatoon and Paddockwood. All three sites experienced winter stress at approximately the Norstar level of winter tolerance. This has provided an excellent screen for cold tolerance. Surviving progeny were screened for height and other agronomic characters. Single plant and row selections were planted at Carlyle, Clair, Watrous, Paddockwood, Porcupine Plain, Saskatoon, Aylsham, Melfort and Indian Head in the fall of 1985. Taller selections were emphasized at the drier trial locations and promising short straw selections were restricted to sites in the more moist regions.

A total of 19 semi-dwarf and normal height introductions and selections from the cold hardiness program were seeded at 13 locations throughout the province in the fall of 1984. There was complete winterkill of all entries at the Saskatoon Kernen Farm and Watrous. Winterkill was experienced in lines with winter hardiness up to the Norstar level at Maidstone, Handel, Golden Prairie, Tisdale, Kipling, Outlook, Paddockwood, Clair and the Saskatoon Preston Avenue Farm. No winter damage was observed at Kamsack or Somme. Consequently, other than excellent measures of winter hardiness, the only meaningful agronomic information on these lines in 1985-86 was obtained at Kamsack and Somme.

EXPERIMENTAL METHODS

Recognized scientific procedures are utilized in all aspects of this program. All trials are replicated. The book on winter wheat management was written by this project. These procedures are followed in all experiments and improvements are incorporated immediately. Many trials are conducted on commercial farms. However, off-station programs are expensive and so most of this work is funded through separate contracts.

RESULTS AND DISCUSSION

The main characters selected for in this program have been winter hardiness, yield, straw length, straw strength, kernel hardness, kernel shape, kernel color, protein and disease resistance (when natural epidemics occur).

Winter wheat usually matures before rust becomes a problem in Saskatchewan. Since rust usually enters the southeast corner of the Canadian prairies first, farmers were warned that the risk of rust damage existed in some years in southern Manitoba and southeastern Saskatchewan. As a consequence of the greater potential for rust damage in Manitoba, the Plant Science Department, University of Manitoba, initiated a backcross program to introduce stem rust resistance into Norstar several years ago. Due to the limited long-term resources available to winter wheat breeding programs in western Canada, it was concluded that a duplication of this effort in Saskatoon should not receive a high priority. However, events of the past growing season indicate that more active consideration must be given to rust resistance in the CDC winter wheat program if variety release is to continue to be an objective. In the past, where possible, parents possessing at least moderate levels of rust resistance have been selected for hybridization, however, priority has been given to other important agronomic and quality characters. Selection for rust reaction was to be made when natural rust epidemics occurred. The limitations to this procedure were evident in 1986 when test sites for rust screening, located in the eastern part of Saskatchewan (rust hazard area) escaped rust damage due to good management practices. Consequently, although breeding material from the Crop Development Centre program was out for screening during the most severe rust epidemic since 1954, little useful information on rust reaction was gained in 1986. It is obvious that a more direct approach to rust screening is necessary. The Crop Development Centre program is priorized through the resources available from contracts. Application for support of an artificial rust screening program was rejected by funding agencies. Consequently, only limited action can be taken to correct this deficiency in the CDC program.

Based on performance in 1985-86 for the other characters listed above, 121 lines were advanced to preliminary yield trials in the 1986-87 Crop Development Centre breeding program at sites near Carlyle, Clair, Paddockwood, Porcupine Plain, Watrous and Saskatoon. Seventy-nine lines were entered into advanced yield trials in 1986-87 at Carlyle, Clair, Paddockwood, Porcupine Plain, Watrous, Saskatoon, Indian Head, Swift Current and Melfort. One thousand, three hundred and eighty-four single lines were planted in the fall of 1986 at Carlyle, Clair, Porcupine Plain and Saskatoon.

CONCLUSIONS AND IMPACT

Management has been the key to the expansion of winter wheat in Saskatchewan and it still continues to be a primary problem area. For example, a difference in seeding depth of 2.5 cm compared to 5 cm often meant the difference between a crop and no crop following the high stress winter of 1984-85. Similar observations were made following the winter of 1985-86, only in this instance the use of starter phosphate fertilizer was critical to survival in many areas. In addition,properly managed winter wheat fields matured early and avoided the severe stem rust epidemic of 1986.

In addition to the major impact of a crop versus no crop because of winterkill or rust, there are many simple, inexpensive management factors that have a large influence on the farmers' net returns. The importance of some of these factors have been detailed in the individual projects reported in this section.

EFFECT OF THE Rht GENE CONDITIONING THE SEMI-DWARF CHARACTER ON COLD HARDINESS IN WINTER WHEAT (*Triticum aestivum* L. em Thell).

D.J. Gilliland and D.B. Fowler
Crop Development Centre
University of Saskatchewan
Saskatoon, Saskatchewan
Canada S7N 0W0

ABSTRACT

In the northern part of the North American Great Plains, the level of cultivar winter hardiness required for winter wheat (Triticum aestivum L.) production is extremely high. Presently available winter wheat cultivars with superior cold hardiness are tall and, under favorable growing conditions, crop lodging and excessive amounts of straw can present serious production problems. Consequently, cultivars with short, stiff straw and a high harvest index would be desireable for high production areas within this region. However, semi-dwarf cultivars with superior cold tolerance have not yet been developed.

In this study, six GA-insensitive (Rht) semi-dwarf parents with poor to moderate cold hardiness were crossed with three GA-sensitive (rht) tall parents possessing good cold hardiness to produce 20 different single, three-way and double crosses. These crosses were evaluated to determine if the semi-dwarf character could be combined with a high level of cold hardiness in winter wheat. Gibberellic acid (GA) sensitivity analyses of F_2 seedlings established that a single GA-insensitive gene was involved in each cross. F_2-derived F_3 and F_3-derived F_4 lines were assessed for GA-sensitivity and cold hardiness levels were determined from field survival at several locations in Saskatchewan, Canada. Winter survival of homozygous GA-sensitive and GA-insensitive lines were similar in both generations. Lines with cold hardiness levels similar to those of the three tall parent cultivars were recovered in all GA-response classes. The absence of a meaningful pleiotropic effect of Rht genes on cold hardiness indicates that the reason semi-dwarf cultivars with superior cold hardiness levels have not been developed is due to the lack of a concentrated breeding effort to combine the two characters. A breeding strategy for the production of adapted cold hardy semi-dwarf winter wheat cultivars is discussed. The influence of endogenous gibberellin levels on cold hardiness in winter wheat is also considered.

Additional index words. Winter hardiness, Field survival, *Triticum aestivum*, semi-dwarf, Gibberellic acid.

Winter wheat cultivars with superior cold hardiness are tall and, under favorable growing conditions, crop lodging and excessive amounts of straw can present serious production problems. Consequently, the development of cold hardy semi-dwarf cultivars with stiff straw and a high harvest index would provide an important alternative for high winter stress regions with favorable growing seasons i.e., the high production regions of the Canadian prairies. However, the cold hardiness levels of commercially available semi-dwarf cultivars has been poor compared to normal, tall winter wheat cultivars.

Several possibilities for the apparent difficulty in developing cold hardy semi-dwarf winter wheat cultivars have been put forth. These possibilities include a close linkage of genes for semi-dwarfism and poor cold tolerance (Fowler et al. 1983), a pleiotropic effect of genes controlling the semi-dwarf character which preconditions the plant to low cold tolerance, e.g., elevated gibberellic acid (GA) levels that interfere with the full expression of genes conditioning cold hardiness (Fowler et al. 1983), and the absence of a concerted breeding effort to combine the two characters (Fowler et al., 1983; Thomas and Gaudet 1983). The objectives of this study were to assess these alternatives and determine if the semi-dwarf character can be combined with a high level of cold hardiness in winter wheat.

MATERIALS AND METHODS

Plant populations

Six semi-dwarf parents with poor to moderate cold hardiness levels (FSI <440) were crossed with three tall parents with good cold hardiness levels (Table 1) to provide 20 different single, three-way and double crosses (Table 2). F_2 seed from each cross was sown into standing rapeseed (*Brassica campestris* L.) stubble in the fall of 1983 at Saskatoon and Outlook (52^{o}N Lat, 107^{o}W Long) Saskatchewan under non-irrigated and irrigated conditions, respectively. Experimental design was a randomized complete block with two replicates at each location. In these and all subsequent field trials, plots consisted of one row, 5.5 meters long, with approximately 90 seeds per row. Row spacing was 30.5 cm. A minimum of five single plant selections were taken at plant maturity from each F_2 row of the 20 different crosses.

F_3 seed from 437 F_2 single plant selections was sown into standing rapeseed stubble in the fall of 1984 at Outlook on irrigated land and at Paddockwood (54^{o}N Lat, 106^{o}W Long) Saskatchewan on non-irrigated land. The experimental design was a randomized complete block with two replications at each location. A Norstar check was included every 20 rows. A minimum of 20 seeds were saved from each F_2 plant selection for GA sensitivity analysis. Severe winterkill necessitated the abandonment of the Paddockwood site in the spring of 1985.

Four hundred and sixty nine single plants were randomly sampled from the F_2-derived F_3 lines grown at Outlook in 1985. F_4 seed from these single plants was sown in the fall of 1985 into standing rapeseed stubble.

mustard (Sinapis alba L.) stubble, barley (Hordeum vulgare L.) stubble and summerfallow at Paddockwood, Carlyle (50°N Lat, 102°W Long), Clair (52°N Lat, 104°W Long) and Porcupine Plain (53°N Lat, 103°W Long) Saskatchewan sites respectively. Experimental design was a randomized complete block with one replicate at each site. A Norwin check plot was included every 20 rows.

Cold hardiness determination

In the spring of 1985 and 1986, percent winter survival was determined for each F_2-derived F_3 and F_3-derived F_4 line. These values were then utilized to calculate a Field Survival Index (FSI) for each line according to the procedure outlined by Fowler et al. (1983). FSI is a precise, highly heritable measure of winter hardiness for cereals grown in high cold stress environments (Fowler et al. 1981). Differences in cultivar FSI reflect average percent differences expected in field survival, e.g., Ulianovka versus Norstar = 530 - 514 = 16% difference in expected winter survival potential (Table 1).

Gibberellic acid response

Remnant F_2-derived F_3 seed from the 437 single plants selected in 1984 was tested for the presence of Rht genes using a modification of the GA response technique utilized by Gale and Gregory (1977). Seeds from each selection were sown embryo side up in 31 cm by 13.5 cm by 10.5 cm plastic tanks. The seeds were placed one cm deep in a vermiculite medium and covered by a 0.5 cm layer of sand. Each row was 15 cm long with three cm between rows. A semi-dwarf and a tall check cultivar were included in every sixth tank. Each tank was watered with 1000 ml of modified one-half strength

Hoagland's solution containing 10 ppm GA. Tanks were placed in a growth cabinet and held in the dark for 48 h at 2°C to allow the seed to imbibe. The thermophotoperiod was then modified to a 20°C/16 h day and 15°C/8h night. Tanks were watered daily with 250 ml of the Hoagland's - 10 ppm GA solution. Lines were rated after the seedlings reached the two-leaf stage (approximately 12 days) as homozygous GA-insensitive (Rht Rht), segregating for GA response or as homozygous GA-sensitive (rht rht).

GA response ratings for F_3-derived F_4 lines were based upon the GA response ratings of the F_2-derived F_3 lines from which the parent plant was sampled. F_3-derived F_4 lines which originated from homozygous GA-insensitive or GA-sensitive lines were classified as GA-insensitive or GA-sensitive, respectively. The GA response of the F_4 lines obtained from segregating F_2-derived F_3 lines could not be determined as the parent plant could be one of three possible Rht genotypes. Plants sampled from these lines were dropped from further analyses.

The pedigree's of the semi-dwarf parents used in this study (Table 1) indicated that each was a potential source of two Rht genes. Therefore, the number of Rht genes carried by each of the six semi-dwarf parents was estimated from the F_2 segregation ratio in a GA response test of crosses with the three tall parents (total of 18 single crosses). Segregation for GA response was also determined for the F_2 generation of complex crosses involving both Plainsman 5 and Vona (Table 2) to establish if these two cultivars carried the same Rht gene.

RESULTS AND DISCUSSION

Chi-square tests indicated that the F_2 segregation for GA response fit an expected single gene ratio of 1 GA-insensitive (Rht Rht):2 intermediate (Rht rht):1 GA-sensitive (rht rht) in 15 of the 18 single cross families. The three families which deviated from the expected ratio were observed in three different test-crosses of semi-dwarf with normal, tall parents. The N/723 F_2 family had a higher than expected score for the GA-insensitive phenotype and both N/V and A/P F_2 families had higher than expected scores for the GA-sensitive phenotype. Nonsignificant homogeneity chi-square values justified the pooling of results within each test-cross except for the two sets testing Plainsman 5 and 723. The summed data for the remaining sets fit the expected 1:2:1 ratio for a single Rht gene.

In a comparable study Gale and Gregory (1977) also observed F_2 families which diverged from a 1:2:1 ratio. In their study 23 of 25 F_2 families did not fit the expected ratio. Twenty-one of these deviating families had higher than expected numbers of the GA-sensitive phenotype. On the basis of these results they proposed that Rht gametes competed poorly with rht gametes. However, the large number of families with segregation for GA-sensitivity which fit an expected 1:2:1 ratio for a single gene discounts the theory of differential gametic competition for the gene(s) under consideration in the present study. In addition, although two of the deviating F_2 families had higher than expected numbers of the GA-sensitive phenotype, one of the families had a higher than expected number of GA-insensitive phenotype. The latter result would not be expected if the Rht gamete competed poorly with the rht gamete.

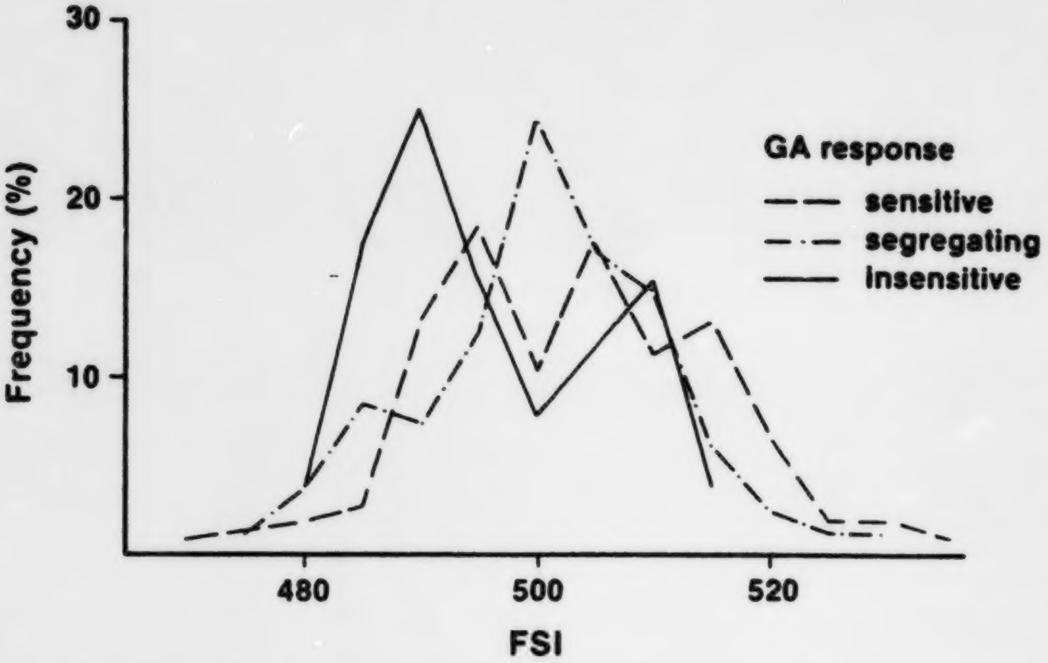

Figure 1. Frequency distributions for Field Survival Index (FSI) of three GA response classes of F_2-derived F_3 lines.

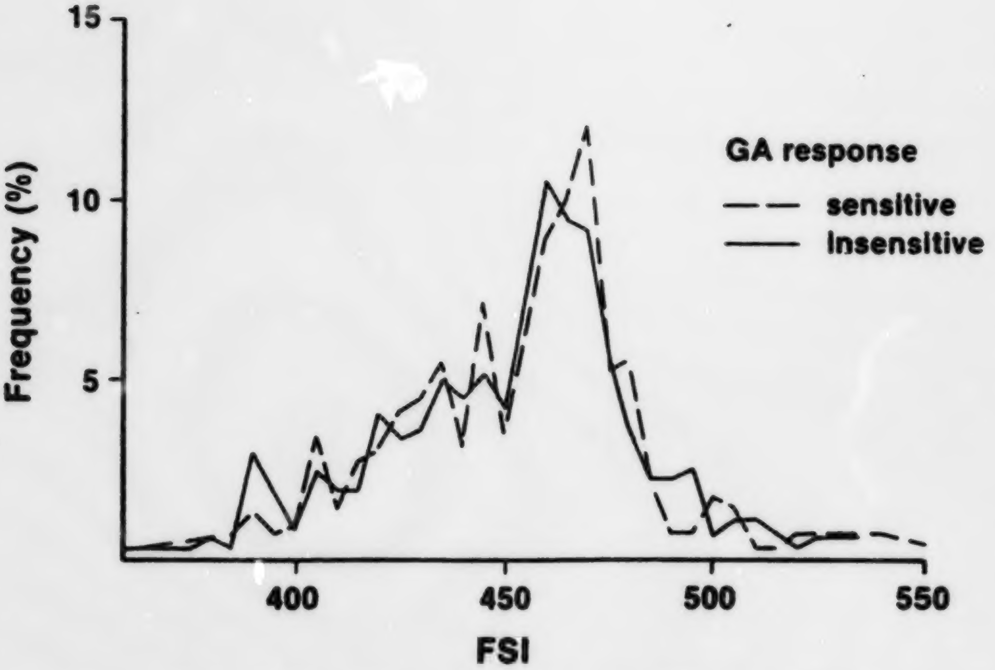

Figure 2. Frequency distributions for Field Survival Index (FSI) of two GA response classes of F_3-derived F_4 lines.

F_2 segregation for GA response in the Plainsman 5 by Vona three-way and double crosses (Table 2) indicates that the short stature of these two semi-dwarf cultivars is conditioned by the same Rht gene. Families segregating for GA response were tested for goodness of fit to a 1:2:1 ratio and no deviations were detected. Furthermore, four crosses were found to have F_2 populations which were totally GA-insensitive. This condition could only occur if the Rht genes conditioning the semi-dwarf character in these two parents were identical.

The parental pedigrees of the semi-dwarf cultivars considered in this study indicate that Rht1, Rht2 and Rht3 may be present (Table 1). Unfortunately, the identity of the Rht gene cannot be accurately determined by the straw length of the six parental cultivars due to the confounding influence of background genotype on the expression of height (Gale and Youssefian 1985). Identification of the Rht gene would require that the semi-dwarf parents be crossed to tester lines known to possess the Rht1, Rht2 or Rht3 gene and the F_2 segregation scored. However, it has been established that a single GA-insensitive gene is involved in each cross and the actual identity of the Rht gene contributed by the semi-dwarf parents is not necessary to the objectives of the present study.

Mean FSI was significantly lower for GA-insensitive than intermediate and GA-sensitive lines in the F_2-derived F_3 generation (Table 3). However, this difference was only seven FSI units at its extreme and therefore not very meaningful in biological terms (Fowler et al. 1981). Significant differences were not observed between GA-sensitive and GA-insensitive lines in the F_3-derived F_4 generation (Table 3).

Differences in mean FSI for crosses (Table 2) were significant ($P \leq .01$) in both the F_2-derived F_3 and F_3-derived F_4 generations. Mean FSI were higher for backcross compared to single and double cross populations. However, considerable variability for FSI existed in all populations. The absence of a significant ($P > .05$) cross by GA response class interaction allowed for the pooling of data for comparison of population distributions among GA classes (Fig. 1 and 2). Differences in population distributions reflected differences in mean FSI for the GA response classes considered in each generation. Lines with FSI equivalent to those of the three tall parent cultivars were recovered in all GA classes (Table 1, Fig. 1 and 2).

Comparison of mean FSI (Table 3) and the population distributions (Fig. 1 and 2) for the GA response classes of the F_2-derived F_3 and F_3-derived F_4 reveals considerable differences between generations. The lower FSI for the F_3-derived F_4 are a reflection of the lower cold stress levels encountered in the winter of 1985-86 compared to 1984-85 (Table 4). Only plots with differential winterkill can be utilized in the calculation of FSI and, as a result, 19 percent of the GA-insensitive and 23 percent of the GA-sensitive lines with 100 percent survival were excluded from the 1986 analyses (Table 5).

The absence of a meaningful pleiotropic effect of Rht genes on cold hardiness indicates that the reason semi-dwarf cultivars with high levels of cold hardiness have not been developed is due to the lack of a concentrated breeding effort to combine the two characters. F_3 and F_4 frequency distributions for FSI (Fig. 1 and 2) illustrate that excellent cold hardiness levels can be attained in GA-insensitive Rht lines. In fact, 34 percent of the F_3-derived F_4 semi-dwarf lines (Fig. 2, Table 5) had FSI values greater than that of the most cold hardy semi-dwarf cultivar (Norwin FSI = 470) which is presently commercially available (Taylor et al. 1986; Fowler 1986).

The breeding strategy to produce short stature cultivars with superior cold hardiness should be relatively straightforward because the semi-dwarf character is conditioned by single genes that are expressed in GA-sensitivity seedling tests. The backcross method is particularly suitable for transferring single, readily identifiable characters from one line to another and, consequently, should provide a simple, effective method for moving the Rht genes into adapted, winter hardy, genetic backgrounds. Since the interaction between cross and GA-sensitivity class was nonsignificant in the present study, the choice of semi-dwarf parents does not appear to be a limitation. The main difficulty in the procedure can be expected in the identification of cold hardy semi-dwarf lines. Preliminary screening for cold hardiness can be achieved utilizing any one of many prediction tests (Fowler et al. 1981). However, field survival is the ultimate measure of a line's cold hardiness (Fowler et al. 1981) and, as demonstrated in this study, ideal test winters for field screening can be elusive. Multiple locations increase the chance of subjecting the test material to adequate cold stress. However, results from more than one winter will probably still be required to provide satisfactory final estimates of a line's cold hardiness.

The lack of a pleiotropic effect of Rht genes on cold hardiness has implications with respect to the influence of gibberellins on cold hardiness in winter wheat. Endogenous gibberellin levels are relatively high in GA-insensitive semi-dwarf cultivars compared to normal, tall cultivars (Radley 1970; Gale and Marshall 1975). However, in this study, higher endogenous gibberellin levels in the GA-insensitive lines were not reflected in meaningful differences in the cold hardiness levels of the semi-dwarf and normal, tall populations. These observations indirectly support the concept that endogenous gibberellins have a limited influence on the cold hardiness [illegible] winter wheat (Roberts 1971; 1974; Wrightman 1979).

ACKNOWLEDGEMENTS

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Table 1. Pedigrees of parents.

Parent	Abbreviation	Pedigree
Semi-dwarf		
Vona	V	Andes 64A/Sonora 64^{++}//Tacuari/4/Warrior//Kenya 58/Newthatc 2*(Cheyenne/Tenmark/Mediterranean)/Hope/3/Parker/5/ Norin 16 $^{+ \text{ and } ++}$/3/Nebraska 60//Mediterranean/Hope/4/Kaw. (Welsh et al. 1978).
Plainsman 5	P	Complex pedigree which includes Daruma $^{+ \text{ and } ++}$
723	723	Yamhill/Tobari 66^{++}//Vona$^{+ \text{ and } ++}$/Bluebird 24^{+}
724	724	Yamhill/Tobari 66^{++}//Vona$^{+ \text{ and } ++}$/Bluebird 24^{+}
10	10	Tom Thumb^{+++}/Cappelle-Desprez//Tobari 66^{++}
11	11	Tom Thumb^{+++}/Cappelle-Desprez//Tobari 66^{++}
Tall		
Norstar	N	Winalta/Alabaskaja (Grant 1980). FSI = 514
Ulianovka	U	sel. from Belokosky awnless-USSR introduction. FSI = 530.
Alabaskaja	A	Hybrid BC 20 (Tepskoy) - USSR introduction. FSI = 527.

+,++,+++- Possessing the Rht1, Rht2 or Rht3 gene respectively.

- Seed supplied by Goertzen Seed Research, R.F.D. 2, Box 248, Scott City, Kansas 67871
- Seed supplied by W. Johnston, Great Plains Seeds and Research, 410 E. Bryant, Bozeman, MT 59715.

Table 2. Summary of crosses. See Table 1 for abbreviations.

Single crosses	Three way crosses	Double crosses
10/A	N/V//U	N/V//V/A
N/11	N/P//U	N/V//P/U
11/A	N/V//N	N/V//A/V
724/A	N/V//A	N/V//P/N
U/723	N/P//V	N/P//A/V
	N/V//P	N/P//P/U
	P/N//V	N/V//N/P
		N/P//V/U

Table 3. Mean FSI of GA response classes for F_2-derived F_3 and F_3 derived F_4 lines.

	F_2-derived F_3 lines		F_3-derived F_4 lines	
GA response	n	Mean	n	Mean
Sensitive	108	503 a	291	454 a‡
Segregating	82	501 a		
Insensitive	52	496 b	362	452 a

[†] Means followed by the same letter are not significantly different at the 5 perce level as tested by a Duncan's New Multiple Range Test and ‡ an F test.

Table 4. Minimum Field Survival Index (FSI) required to give 100 percent survival of check plots at 1984-85 and 1985-86 test sites.

Year	Location	Mean FSI	n	FSI Range
1984-85				
	Outlook	588	103	555-610
1985-86				
	Carlyle	496	44	470-555
	Clair	483	50	470-565
	Paddockwood	496	54	470-565
	Porcupine Plain	489	62	470-560

Table 5. Number of semi-dwarf (Rht Rht) and tall (rht rht) lines with 100 percent or 0 percent winter survival in 1985-86.

Genotype	100% survival	0% survival	Total no. lines
RhtRht	101	34	529
rhtrht	109	28	469

CONCLUSIONS AND IMPACT

A number of high performance lines have been entered into advanced screening trials in 1986-87. However, another year or two of testing will be required to establish the strengths and weakness of these lines and determine their potential as varieties.

The Montana State semi-dwarf winter wheat cultivar "Norwin" was registered for commercial production in Canada through the Crop Development Centre program. In February 1986 the Expert Committees on Grain supported a request from the Crop Development Centre, University of Saskatchewan, that the winter wheat MT7877 be registered for commercial production by Western Canadian Farmers. MT7877 was developed at Montana State University by Dr. Allen Taylor. It has been tested extensively in the northern great plains region of the U.S.A. and was released for production there in 1985 under the name Norwin. Tests conducted in 1981 and 1982 in Saskatchewan established Norwin as the most winter hardy semi-dwarf wheat available. Subsequently, twenty-six station-years (1982/83, 1983/84 and 1984/85) of data have been accumulated comparing the agronomic performance of Norwin with Norstar in western Canada. With the exception of height and winter survival, the agronomic performance of Norwin has been similar to Norstar. Because of the poor winter hardiness of Norwin, growers in areas with even a moderate risk of winterkill should approach the production of this cultivar with caution. The most likely areas of adaptation are south-western Alberta, British Columbia and the northern edge of the prairie parkbelt. Norwin will appeal to producers in these high productivity, low winter stress regions because of its short straw and its superior harvest handling characters. Producers in the remainder of western Canada should continue to grow Norstar.

Four hundred and fifty-nine kg of breeders seed and 884 kg of select seed were distributed to 15 pedigreed seed growers in Alberta, Saskatchewan and Manitoba in the fall of 1986. This seed was produced by the Crop Development Centre. Further increases will be made exclusively by Montana State University. Norwin was released as a public variety in Canada.

C1 CROP DEVELOPMENT CENTRE GENETICS PROGRAM 1986-87

THE INTERSPECIFIC TRANSFER AND EXPRESSION OF ALIEN COLD-HARDINESS GENES IN WHEAT

A.E LIMIN AND D.B. FOWLER

ABSTRACT

Production of a Nullisomic Series in Triticale

The expression of rye cold-hardiness genes in triticale appear to be suppressed in the presence of the wheat genome. On the hypothesis that some wheat chromosomes may carry a gene or genes responsible for this suppression, nullisomic lines (missing one pair of chromosomes, 2n=54) have been produced for most wheat chromosomes. If this hypothesis is true then removal of the suppression carrying chromosomes should result in a line exhibiting greater expression of the rye cold-hardiness genes. Some lines still remain to be produced and there is poor fertility in other lines. Those lines which are reasonably fertile have been run in a preliminary freeze test. The cold hardiness rating of most lines was near the same value as the parent triticale of normal chromosome number (2n=56). However, at least one nullisomic line is more cold hardy than the parent. These preliminary results indicate that at least one wheat chromosome may in fact carry a suppressor of rye cold hardiness genes.

Mutation of Wheat 'Suppressor' Genes in Triticale

If there are genes in wheat which suppress the expression of rye cold hardiness genes in triticale, then it may be possible to inactivate these suppressors by using a suitable mutation agent. This would allow exploitation of the superior cold hardiness genes of rye for wheat improvement.

Hexaploid triticale seed has been treated with the mutagenic agent EMS (ethyl methanesulfonate). These plants are now being grown to maturity to produce seed for cold hardiness evaluation.

The Expression of Alien Cold Hardiness Genes in Wheat

Interspecific combinations of a number of potential donor species with wheat revealed a wide range of cold hardiness levels in the hybrid or amphiploid. In the wheat-rye amphiploid, triticale, there was no expression of the rye cold hardiness genes. However, in hybrid combinations of wheat and tall wheatgrass, the hybrid plants were similar in hardiness to the hardy wheatgrass parent. Intermediate wheatgrass and **Triticum cylindricum** hybrids with wheat were slightly less hardy and slightly more hardy than the parental midpoint values, respectively. There was a general tendency for the species with the largest chromosome number to have the greatest influence on cold hardiness.

A new amphiploid was produced combining the diploid genome of a very cold hardy crested wheatgrass with 'Chinese Spring' wheat. Unfortunately, there was no expression of the crested wheatgrass cold hardiness genes in the amphiploid. It, therefore, appears that the cold hardiness genes of diploid species (e.g. rye and crested wheatgrass) are poorly expressed in the presence of the wheat genome. However, it was found that wheat-rye hybrids, containing only half of

the chromosome number of the triticale amphiploid, were more cold hardy than either the amphiploid or the wheat parent. This increase in cold hardiness appears to be due to the smaller cell size associated with a reduced chromosome number. This has implications in the interpretation of gene expression in interspecific hybrids and amphiploids. When the cell size in an interspecific hybrid combination is reduced relative to the hardy parent, the hybrid may appear to show dominance for cold hardiness when in fact the unexpected hardiness is due to smaller cell size. The converse of this situation may also be true, making the genes of hardy diploid genomes appear recessive.

Based on the results of this work, it appears that chromosome dosage and cell size must be taken into consideration when evaluating possible gene donors in interspecific combinations.

Production of Alien Substitution Lines in Wheat

Since some wheat chromosomes may actually suppress the expression of superior alien cold hardiness genes, the substitution of the alien chromosome in place of the wheat chromosome may confer a significant cold hardiness advantage to wheat. In this way the suppressor genes of wheat will be removed and replaced with alien chromatin which may carry superior cold hardiness genes which will then be more fully expressed. Unlike amphiploids, these substitution lines will not have larger cell size to further inhibit cold hardiness expression.

Two of the most cold hardy wheat cultivars, rye and crested wheatgrass, are being used as gene donors. Related wheatgrass chromosomes will replace the B genome chromosomes of wheat, and rye chromosome will be substituted into the A genome of wheat. Backcrossing of wheat-rye or wheat-crested wheatgrass amphiploids to the Chinese Spring monosomic series has been successful, and seed is now being set on the second backcross generation of some lines.

INTRODUCTION

It is apparent from the lack of progress in breeding greater cold tolerance into winter wheat over the last 75 years, that new gene sources are required. However, cold-hardiness genes from rye, the most cold-tolerant cereal, are suppressed in the presence of the wheat genome in triticale. We have found, however, that cold hardiness genes from speices of the **Agropyron** genus may show greater expression than those of rye when combined with wheat. In this same report it was also shown that crested wheatgrass was amongst the most cold hardy species of the **Agropyron** genus. This year's work has been aimed toward further understanding the expression and suppression of alien cold hardiness in wheat.

EXPERIMENTAL PROCEDURES - RESULTS AND DISCUSSION

Project I - Production of a nullisomic series in triticale.

Purpose - To produce a series of lines each with one particular pair of wheat chromosomes missing. If any particular wheat chromosome is carrying a suppressor of rye cold hardiness genes, then its absence should remove that suppression and produce a more cold hardy triticale line.

Progress - Nullisomic lines have been produced for most of the wheat chromosomes in triticale, however, a few lines still remain to be developed. Various degrees of sterility in some lines has limited seed production. Preliminary experiments with a small number of plants suggests that at least one wheat chromosome does in fact suppress the expression of rye cold hardiness genes. This line appears to have greater cold hardiness than the parental line with the complete set of wheat chromosomes. Work is continuing to produce the complete nullisomic set of lines and to acquire adequate seed of each line for freeze testing.

Project II - Mutation of wheat 'suppressor' genes.

Purpose - To use a mutagenic agent to 'knock out' possible suppressor genes present in the wheat genome and thereby allow greater expression of rye cold hardiness genes in triticale.

Progress - The mutagenic agent EMS has been applied to triticale seed and these plants are now being grown to maturity. Seed from these plants will be evaluated for cold hardiness.

Project III - The expression of alien cold hardiness genes in wheat.

Purpose - To determine the type and degree of alien cold hardiness gene expression in wheat, with the goal of selecting a species with the greatest potential for wheat improvement.

Progress - The cold hardiness of a number of wheat x related species combinations was reported last year. Further evaluation of this material, plus some new combinations, has continued this year (Table 1).

When related species were combined with non-hardy wheat the resulting hybrid or amphiploid combination ranged in cold hardiness from that of the non-hardy parent (wheat x rye) to close to that of the hardy parent (wheat x tall wheatgrass). Intermediate wheatgrass and **Triticum cylindricum** combinations with wheat tended to be slightly above or below the parental midpoint. These interspecific combinations appear to illustrate different types of gene expression, dependent upon the donor species used in the cross. In general, the species with the greatest chromosome number had the greatest influence on cold hardiness.

A new amphiploid was produced combining a very hardy diploid crested wheatgrass (**Agropyron cristatum** cv. Parkway) with a non-hardy wheat. The cold hardiness of this amphiploid was unfortunately at approximately the same level as the non-hardy wheat parent. It, therefore, appears that the cold hardiness of the diploids (e.g. crested wheatgrass and rye) are poorly expressed in combination with wheat.

An interesting result was found when a wheat-rye hybrid, as opposed to the chromosome doubled amphiploid, was evaluated for cold hardiness. It was found that the F_1 hybrid had greater cold hardiness than the wheat parent or the amphiploid.

Since the genetic constituent of these hybrids should be the same as the amphiploid, but with one-half of the chromosome numbers, this increased hardiness of the hybrid must be due to reduced cell size associated with the reduced chromosome number. When this observation is generalized across all interspecific combinations, a hardy parent with a high chromosome number will appear to have greater expression of its cold hardiness genes when in combination with a less hardy parent of lower chromosome number because in effect the cell size of the hybrid is smaller. For example, the tall wheatgrass (2n=70) x wheat (2n=42) hybrid will have a chromosome number of 56 making its cell size smaller than that of the tall wheatgrass parent. Based on other combinations an intermediate type of inheritance could be expected, however, the reduced cell size permits greater cold tolerance in the hybrid bringing its actual cold hardiness level close to that of the hardy tall wheatgrass parent. Similarly, when a hardy parent with a low chromosome number is crossed to wheat (e.g. wheat 2n=42 x rye 2n=14) the hybrid will have poor cold hardiness because of the increased cell size (2n=28 vs. 14). It appears then, based on these results, that chromosome dosage and cell size are important factors in cold hardiness expression.

Table 1. The Cold Hardiness (LT_{50}) of Cereal Interspecific Combinations and Their Parents.

Line		Chromosome number	LT_{50}
Triticum aestivum cv. Chinese Spring		42	-11
Thinopyrum ponticum tall wheatgrass c.v. Orbit		70	-23
F_1 hybrid		56	-22
Midpoint			-17
Triticum aestivum cv. Chinese Spring		42	-11
Thinopyrum intermedium intermediate wheatgrass cv. Clarke		42	-22
F_1 hybrid		42	-15
Midpoint			-16.5
Triticum aestivum cv. Chinese Spring	AABBDD	42	-12
Triticum cylindricum	CCDD	28	-21
F_1 hybrid	ABCDD	35	-18
Midpoint			-16.5
Triticum aestivum cv. Norstar	AABBDD	42	-22
Triticum cylindricum	CCDD	28	-22
F_1 hybrid	ABCDD	35	-24
Triticum aestivum cv. Chinese Spring	AABBDD	42	-11
Secale cereale cv. Puma	RR	14	-28
Triticale amphiploid	AABBDDRR	56	-11
Triticum aestivum cv. Chinese Spring	AABBDD	42	-11
Secale cereale cv. Puma	RR	14	-28
F_1 hybrid	ABDR	28	-15
Triticum aestivum cv. Chinese Spring	AABBDD	42	-11
Agropyron cristatum crested wheatgrass cv. Parkway	PP	14	-29
Amphiploid	AABBDDPP	56	- 9

Project IV - Production of alien substitution lines in wheat.

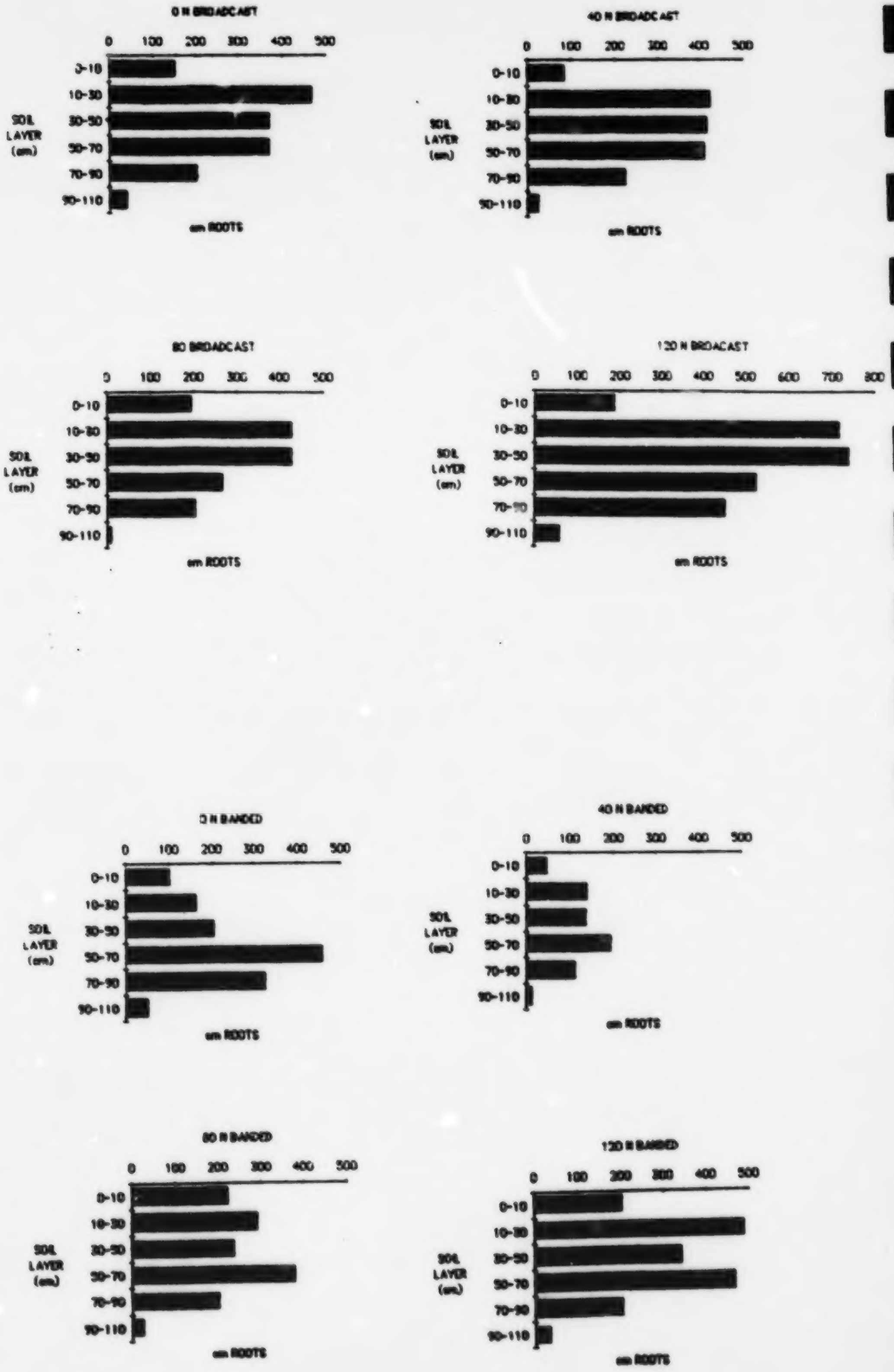
Purpose - Since some wheat chromosomes may actually suppress the expression of superior alien cold hardiness genes (Project I), the removal of these chromosomes and their replacement (substitution) by the related alien chromosome may effectively confer a significant cold hardiness advantage to wheat. This method would also eliminate the deterimental effect of increased cell size (Project III).

Progress - Two of the most cold hardy wheat relatives (rye and crested wheatgrass) are being used as chromosome donors. The wheat x crested wheatgrass amphiploid, produced in Project III, has been found to backcross well to wheat and the second generation of backcrossing is in progress. Related wheatgrass chromosomes will replace the B genome chromosomes of wheat. The nullisomic triticale series being produced in Project I will be used to substitute rye chromosomes into the A genome of wheat. The first backcross generation is now being produced on the appropriate wheat monosomics.

CONCLUSIONS AND IMPACT

The ultimate goal of this project is the production of a super-hardy winter wheat, i.e. rye cold hardiness level. This is important if winter wheat is ever to be produced successfully utilizing traditional production methods, i.e. seeded into tilled seedbeds, or if the winterkill risk is to be reduced for the stubbling in management system. Limits to genetic variability in the wheat gene pool appear to have rendered traditional breeding approaches ineffective in producing super-hardy wheats. So far, less traditional approaches have been equally unproductive and the experiments reported in this study are the first positive indications that progress can be made through interspecific gene transfer using a combination of biotechnology and traditional cytogenetic techniques. However, it must be emphasized that major progress toward the production of a super-hardy winter wheat can still only be expected to come slowly, and with well designed basic research projects such as the ones reported on in this summary.

Figure 6. Perdue 1985



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